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PSYCHOBIOLOGICAL MECHANISMS IN COMPLEX MENTAL PROCESSES AND THEIR CHANGES WITH AGE.

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INTERRELATIONS AMONG PHYSIOLOGICAL AND PSYCHOLOGICAL VARIABLES OPERATING DURING PROBLEM-SOLVING TRIALS WERE STUDIED. A SIMULTANEOUS ANALYSIS OF THESE VARIABLES AIMS AT A STUDY OF STRESSES DEVELOPING WHEN SUBJECTS ATTEMPT PROBLEM-SOLVING. QUESTION-STUDY INTERPRETIVE TECHNIQUES AND PROBLEMS REFERENCED IN EARLIER REPORTS (ED 003 005 AND ED 003 006) WERE USED. CARDIAC RATES WERE RECORDED CONTINUOUSLY FROM 5 MINUTES BEFORE TO 5 MINUTES AFTER PROBLEM ADMINISTRATION. BASELINE CARDIAC RATES WERE COMPUTED FOR SUCCESSIVE TIMES. PSYCHOLOGICAL AND PHYSIOLOGICAL DATA RELATED TO ALL THE PROBLEMS WERE COLLECTED AND ANALYZED. FOR THE SAKE OF BREVITY, FINDINGS FROM ONLY ONE PROBLEM WERE PRESENTED. PERFORMANCE CURVES WERE PRESENTED WHICH INDICATED THAT THE PSYCHOLOGICAL AND PHYSIOLOGICAL PROCESSES WERE HIGHLY PERSONAL. THEY ALSO INDICATED THAT ATTEMPTS TO INTERPRET PROBLEM-SOLVING ABILITY BY ANALYZING PROBLEM SOLUTIONS WOULD BE MISLEADING. DIRECTIONS AND PLANS FOR CONTINUED RESEARCH WERE REPORTED. (WN)

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Part III

PSYCHOMETRIC LABORATORY

PSYCHOBIOLOGICAL MECHANISMS IN COMPLEX MENTAL PROCESSES AND THEIR CHANGES WITH AGE

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Chapter I

INTRODUCTION

The following report describes part of the work accomplished from October 1961 until now under Research Project No. 1787 on "Psychobiological Mechanisms in Complex Mental Processes and their Changes With Age". We are thankful for the help given to us by members of the board in consultations and technical advice.

The starting date assigned by the Illinois Psychiatric Training and Research Authority was July 1st, 1961, but permission was obtained to begin work on the project starting October 1st, 1961.

During the first two months the personnel was assembled and bibliography pertinent to the project was reviewed. Only after December 1st did the actual experimentation begin. Ideas for new problems to be administered to subjects at different age levels were developed. The autonomic variables to be included in the project were discussed with physiologists and psychobiologists.

It was decided to limit, for the time being, our exploration to cardiac rate as estimated by electrocardiographic recordings. One of the main reasons to determine our choice of variables was the lack of equipment, that we had to borrow through the kindness of Dr. Randall, Chairman of the Department of Physiology of the Stritch School of Medicine. Thanks to the recent favorable decision of the Illinois Psychiatric Training and Research Authority concerning the purchase of equipment for the project, we will increase, in our future work, the number of physiological variables to be explored. Up to the present time we have limited our

study to the experimentation with adults. In the future other age groups will be studied.

The results of this preliminary report of our major investigation cover experimental work fulfilled during the last three months with adult subjects in a limited number of physiological variables.

The work accomplished thus far in this project indicates that the scoring procedures developed are basically sound. Also the development of schema for the construction of problems of graded complexity is, to our best judgement an important contribution to the research project.

In summary, we know now 1) how to develop better problems and vary them in complexity and presentation so that differential performance at different ages can be analyzed, 2) the best physiological indicators to be used in the future in order to fulfill the requirements of our original proposal. From the results thus far obtained we have bases to feel optimistic about our ability to clarify some of the issues raised in our original proposal to the Illinois Psychiatric Training and Research Authority, that is changes in the sequential organization of complex mental processes through age and their relationship to physiological changes that may appear when psychological stress develops as the processes take place.

Chapter II

MAJOR OBJECTIVES OF THE RESEARCH

As stated in our original proposal the purpose of this research is two-fold: "first, the description and analysis of the sequential organization of complex mental processes (i.e., problem solving) and how these change from early life to old age; second, to study the inter-relationship between some physiological and psychological variables that operate when psychological stress develops as the processes take place."

The appraisal of problem solving processes by using a technique that allows for their characterization in terms of the sequences of questions made by the subject when solving a problem has shown that the information thus obtained complements advantageously other commonly used techniques. It has opened up a host of problems concerning the evaluation of higher mental processes, the possibilities of their training and the specificity of personal ways of approaching the solution of problems.

It is expected that our attack of the problem may allow for a better understanding of some psychobiological mechanisms related to growth and ageing as well as the characterization of originality of approach at different age levels.

In research of this type, processes rather than products should be evaluated. Often, interpretation plays a part that transcends observation and/or experimental findings. Our objective is to avoid, in as much as it is scientifically possible, the effect of biases in the general development of the research. In all cases we expect to define, as objectively as possible, the variables and the experimental conditions,

hoping that the experimenter's error will be kept at a minimum.

The simultaneous analysis of physiological variables aims at the study of the stresses that develop while subjects try to solve a problem, as it were, the built in stress, that may accompany the completion of a task. The distortions and changes that occur in pathological conditions may thus be clarified.

Whether or not successful problem solvers, success being understood in terms of process (tactic) rather than products, show concomitant physiological changes, and whether these are related to changes in level or variability may be a finding of significance for both the theory and practice of psychology.

Chapter III

COMMENTS ON RELATED LITERATURE

In previous classical studies of cognitive activity such as those by Thurstone, Spearman and Guilford, emphasis was placed upon the interpretation of responses to problems. Recently, however, attempts have been made to study the "process" involved in problem solving rather than the product as given by the final answer.

Bloom and Broder (3) in their study on "Problem Solving Processes of College Students" were concerned with whether our present measures of achievement and aptitude reflect the quality of a subject's thinking. By having their subjects "think aloud" while solving a problem, they found strong evidence that there is not a linear relationship between thought processes and thought products. Even though their technique was quite subjective, it was a step in the right direction as far as investigating thought processes.

A technique similar to the one employed in this study was developed by Bryan (4) and by Glaser, Damrin and Gardner (9). Both of these methods were used in evaluating trouble shooting in electronics. A discussion of these techniques compared to the one in this study has been presented in other papers (22, 23).

Sequential properties of complex problem solving were described in a study by John and Rimoldi (15). Cognitive processes were discussed in terms of performance on the PSI apparatus (Problem Solving and Information Apparatus). This apparatus may be useful in studying certain phases of abstract reasoning, but can not be used in a variety of

situations where less abstract problems are examined (2).

A series of studies related to the present research have been published by the Loyola Psychometric Laboratory, and the development of the technique has been described in several papers (22, 23, 25, 29). The application of this technique to many different areas also has been discussed in a series of reports from the Loyola Psychometric Laboratory. In the Test of Diagnostic Skills (22) processes leading to medical diagnoses were proposed as a basis of study rather than the final diagnosis (6, 7, 13, 26, 30). This method has also been applied to the appraisal of personality parameters (12), the evaluation of organic factors in brain damaged children (18), the analysis of Rorschach interpretation (34) and decision processes in mathematical thinking (32).

In regard to research relating change of autonomic functions to complex problem solving processes, very little has been reported. Blatt (2) compared the level of cardiac rate and its variability for efficient and inefficient problem solving subjects. Though the two groups of subjects were basically similar in cardiac patterns, there was a highly significant increase in heart rate and variability in the efficient subjects while they were attempting to solve the problems.

Much of the research in problem solving processes emphasizes the effects of stress and anxiety as products of psychological "sets" or other variables built into problems to be solved, and concomitant research relating stress to autonomic functions has been reported extensively (10, 11).

Heath, Oken, Korchin and Towne (14) reported the results of a factor analysis of multiple variables and their changes arising from the

effect of stress. Four of the factors extracted were highly loaded in affect expressed by the subjects and other physiological data. The high loadings in these factors were related to the stress imposed upon the subjects.

Stress and anxiety experienced during psychotherapeutic interviews and their relationships to autonomic functions has been investigated extensively in several studies. Coleman, Greenblatt and Solomon (5) made simultaneous observations of both patient and therapist in forty-four clinical interviews. Their results demonstrated that heart rate is an extremely sensitive sign in indicating momentary shifts in affect, and they concluded that the patient shows the highest heart rate during moments of "anxiety" and the lowest heart rate during periods of "depression". In another study, Anderson (1) found that heart rate and heart rate variability, derived from continuous electrocardiographic recordings on a patient for ten clinical interviews, increased in proportion to the amount of affect expressed in the interview. Similarly, Di Mascio, Boyd and Greenblatt (39) report a case study of a patient for twelve clinical interviews. Electrocardiograms taken on the patient during the interviews indicated that when he manifested "tension release", his heart rate tended to be slow, and when the patient manifested much "tension", his heart rate tended to be fast.

In regard to research on autonomic response patterns and their variability, Wenger (35, 36, 37) intensively studied both children and adults in a number of autonomically innervated functions. Wenger, Engel and Clemens (38) concluded that "the autonomic factor for a given individual tends to remain constant from year to year, but may be altered

phasically or chronically by changes in extrnal or internal stimulation". They also observed that "autonomic factors scores are related to certain personality patterns and to certain diagnostic categories such as anxiety psychoneurosis, battle fatigue, and asthma.

In a somewhat different direction, Lacey (16, 17) emphasizes the importance of considering the effect of response specificity in measuring various autonomic functions, but other research by Schnore (33) indicates that cardiac rate, for example, reflects most consistently the general level of autonomic arousal.

Chapter IV

EXPERIMENTAL PROCEDURE AND DISCUSSION

The five problems described in Appendix A were administered to a group of seventeen subjects. The duration of each experimental session varied from one and half hours to two hours.

The subjects were all male graduate students in psychology between twenty-three and forty years of age. Table 1 shows whether the solution given by a subject to a problem was right or wrong as well as the problems not attempted by some of the subjects.

The subjects were given instructions concerning the problems to be solved. (see Appendix A). Cardiac rate was recorded continuously by means of an electrocardiograph while the subjects were solving the problems, as well as for five minutes before and after the administration of the problems. In this fashion two base lines were obtained, one before and one after testing. Electrodes on the arms and legs were reversed to avoid the interference of movements in the upper limbs because of the movement involved in the selection of the cards. In order to control for the possible effects on heart rate of the bodily movement necessary to solve the tests, that is picking up the cards and returning them to the table, the subjects were required to select blank cards randomly during the pre- and post-testing situations.

A. Cardiac Rate

Baselines

For every subject the cardiac rate was computed for successive

periods of time. Since the tape moved at a regulated constant speed, the number of cardiac events was counted for every centimeter of tape, which represents approximately 4.58 seconds.

For the purpose of graphing figures, moving averages computed on the basis of two successive intervals were calculated. This decision was reached after trying other moving averages based on different interval groupings. From this data graphs were drawn for both the pre- and post-testing base lines. Inspection of these graphs did not show any changes in cardiac rate attributable to the movements involved in the selection of the blank cards every twenty-five seconds. The inspection of these graphs suggested the convenience of making a more detailed statistical analysis of the figures. For instance, the second base line indicated in general a lower cardiac rate than the first base line. Also differences in variability, and range between actual values seemed to be present. The results of the statistical analysis of the first and second base lines for all the subjects are presented in Tables 2 and 3.

In Table 2 the mean, standard deviation, and sigma of the mean are given for each subject for both baselines. In the last two columns the value of the differences between means and the corresponding t values are presented. Notice that in thirteen cases there is a decrement in cardiac rate from the first to the second base line, of which nine of these are significant at the .01 level. Two cases show an increase in cardiac rate in the second base line as compared to the first. For only one of these subjects is the change significant at the .01 level.

A similar comparison was made between the variances of the first and second base lines. Only one subject (subject number two) shows a change that is significant at the .02 level (F test), while for the remaining sixteen the change is not significant.

In Table 3 the results of a more crude test are presented to explore the variability in cardiac rate within each baseline. The values in this table give the range between the highest and lowest heart rate obtained in the first and the second base lines. Subject number two again shows the greatest discrepancy.

In plotting the means and corresponding standard deviations for base line one and base line two (Table 2) no evident relationship is found, that is the variability in rate seems to be independent of the average frequency.

From these findings it seems possible to suggest that in spite of changes in rate from one situation to another the variability in cardiac rate is the same for each individual in these two base lines.

B. Test Performance

Cardiac rate was continuously recorded during the solution of each problem. For computing purposes the number of cardiac beats per centimeter of tape were counted. From these observations the corresponding means and standard deviations for each subject in each problem were estimated. These values are presented in Tables 4 and 5. The order of the columns in Tables 4 and 5 corresponds to the order in which the problems were answered. Table 6 presents the range between maximum and minimum cardiac rate per problem and per subject. These

values were computed by plotting the moving averages for each subject of two successive time periods and then estimating the maximum and minimum absolute extremes.

Some preliminary analysis of this data has already been accomplished, and at the present time a multivariate analysis of our findings is being performed. Nevertheless, some results are already forthcoming.

The means presented in Table 4 show the average cardiac rate in different problems for each subject. The study of these means, by using analysis of variance, showing their relationship to successful completion of the problem is in the process of being studied. We expect to find information pertinent as to whether successful problem solving tends to be associated with higher cardiac rates (2).

In Table 5 the standard deviations of cardiac rate measured throughout the performance of each test for every centimeter of tape (approximately 4.58 seconds) are presented. The overall picture seems to indicate that, with few exceptions, these standard deviations are relatively constant for each subject independent of the test being performed. The study of the range of variation, for each test, seems to show a similar trend (Table 6).

In order to analyze whether variability in cardiac rate is constant for each subject, F tests were performed for all the possible combinations of tests among themselves and with both baselines. The results are given in Table 7 whose column headings indicate tests being compared while the rows indicate the subjects.

The last ten columns of Table 7 refer to all the possible com-

parisons of pairs of tests among themselves. The first six columns represent the comparison of the second base line and all of the tests with the first base line, and the five following columns represent the comparison of the second base line with all the tests. The entries in the table should be interpreted as follows: 0 means a nonsignificant difference between variances, a plus sign means that the difference between variances is significant at the .02 level, the variance being greater for the first test is listed at the head of the corresponding columns. If the sign is minus it means significance at the .02 level, the variance being greater for the second test listed at the head of the corresponding columns.

Two subjects did not complete all the tests, as shown by the empty cells in Table 7.

In analyzing the columns of Table 7, the distribution of 0 and significant entries does not seem to show any special trend. Some subjects do show a good number of significant entries in their corresponding row but they seem to be the exception. The results of Table 7 indicate that the number of significant entries does not reach an acceptable level of significance (binomial test). That is, the variability of cardiac rate estimated in successive periods of time is for all practical purposes null, though some subjects may violate this rule.

It is interesting to notice that in several tempo studies (19, 20, 21) it has been repeatedly shown that variations in the rate of performance of a given task is constant for a given subject, under both normal and stress situations. These findings also show that though

there is not a general factor of personal tempo, there are several factors with relatively low correlations among themselves. Thus prediction of tempo for one type of performance to another may be risky unless both performances can be explained in terms of the same underlying factor. Though a factor analysis of subjects' variability in tempo has not yet been performed it is likely, on the basis of our experience, that this may show it to be actually constant. If this is so it may be advisable to study tempo not only as a matter of number of performance units per time unit but also as a matter of constancy of performance units per time unit. In our future research we intend to deal with this problem in order to explore the possibility that physiological variables may be related to psychological tempo through the subjects variability. This may be a fruitful approach since the findings reported before point to the fact that though in the performance of complex mental tasks an individual may show a variety of cardiac rates for the different tasks, the variability of cardiac rate remains essentially constant.

C. Psychological Data

Every one of the seventeen subjects attempted all the problems. Two of them did not complete all of them. Several scoring methods were used in order to evaluate performance. In Table 1 information is given indicating whether the problems were successfully solved. It should be remembered that this is not the only or the most significant evaluation of the process followed by the subject, as it has already been discussed in previous articles (22, 23, 24, 25).

Subjects were scored in terms of the number of cards selected in the solution of a problem (Table 8). The utility indexes for each card (question) were computed by calculating the ratio between the number of times that a question (card) is chosen by the group and the number of subjects in the group.* The values of the utility indexes for each question and for all the problems are given in Table 9. By accumulating the utility indexes in decreasing order of magnitude and plotting these values against successive choices a "maximum" curve is obtained. This curve represents, for the given set of utility indexes, the "best" performance, provided it is accepted that the "best" performance corresponds to a succession of choices that at every step accumulates the maximum possible utility index. The same general type of reasoning can be used to define the minimum curve. The area between the maximum and minimum curve can be used for the purposes of characterizing the test and/or the group on which the utility indexes were computed. In previous studies the details of this approach to the study of processes has been explained (27, 29).

In the present report figures 1 and 2 and 3 show the graphic representation of the maximum and minimum curve for each of the problems used. If all the questions have the same utility indexes, then both the maximum and the minimum curves degenerate into a straight line with a slope equal to the constant utility index. When these indexes are different for different cards, the maximum and minimum will become pro-

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* A correction was used to account for the fact that the subjects used to compute the utility indexes are the same that are scored with these utility indexes. This correction has been fully explained in (30) and can be represented by $U_i = \frac{f-1}{N-1}$, where f = frequency of choice, N = number of subjects and U_i = utility index.

gressively more separated. If some cards have utility indexes of 1.00 and the remaining of .00, then the ellipsoids become parallelograms (31). These parallelograms have been graphed together with the ellipsoids for each problem (Figures 1 and 2 and 3). The ratio between the area of the ellipsoid and the parallelogram is an indication of how different the ratios of the utility indexes are. And it will be greater the sharper the differentiation of the questions in terms of their utility indexes (27, 29).

In our case the subjects were the same, and therefore the ratios permit a differentiation between tests. The greater the values of the ratio, the greater the agreement between subjects as to which questions are more important and which are less important (27, 31). This may also be taken as an indication of the difficulty of the test.

A more refined analysis of the performance should consider the frequency of choice in relation to its order for each question. That is to say, a given question may be asked in first, second, or in nth order with varying frequency. If a question is not chosen by any of the subjects we will say that the order of the question is 0.

In Tables 10, 12, 14, 16, and 18, the frequency of choice of each card in each given order is presented. The 0th row represents frequency with which a given card was not chosen. The Σ_p row corresponds to the sum of the values in each column which is a linear transformation of the corresponding utility indexes. The transformation to be applied in each case is $\Sigma_{p_o} = u_i\left(\frac{N-1}{Nm}\right)+\left(\frac{1}{Nm}\right)$, where N = number of subjects, M = the number of cards and u_i is the utility index.

For each subject in each test it is possible to graph his performance by accumulating the values of the questions in their corresponding orders as presented in Tables 10, 12, 14, 16, and 18. Some of these performances are shown in Figure 13. Notice that the same questions will give different performance curves depending on the order of selection.

Tables similar to those just described can be built by having the values represent those that would correspond to a given hypothesis. For instance distributions based on combinatorial theory were prepared (28) in which the probability of a given question appearing in any ith order (i = 0th, 1st, 2nd, ...ith...nth) is given for sequences composed of k questions (k = 1...k...m). In Tables 11, 13, 15, 17, and 19, the differences between the observed and these hypothesized frequencies (E) are given.

Obviously, if the group proceeds according to the hypothesis, the differences observed minus expected (O-E), should be around 0 except for rounding error. A curve obtained by accumulating for each subject the successive values (O-E) will be farther away (in either positive or negative deviation) from the 0 line. The curve of the performance of the subjects departs from the hypothesis being analyzed.

The accumulation of the observed values of each subject is a summary statement of his performance. Similarly the accumulation of his O-E values is a statement concerning his departure from the hypothesis used to determine the expected values. Plotting on the same graph all the subjects in terms of the accumulation of the O, and O-E values, convex sets are obtained as presented in Figures 4, 5, 6, and 7. A

more detailed rationale and interpretation of the method is presented in (25) and in two unpublished studies (8, 29). Convex sets can also be obtained for questions not asked (0 order). These are presented in figures 8, 9, 10, 11, and 12. It is psychologically interesting to notice that this approach permits to differentiate and a posteriori to integrate for the purposes of interpretation, what subjects do and what they do not do. Also the observed performance can be evaluated in terms of a variety of hypotheses and each subject interpreted in terms of these.

It should be noted that our previous discussion is based on norms obtained from group performance. This is acceptable provided the interest is to order subjects from higher to lower in terms of group performance. But unnecessary confusion in the interpretation of the results may arise because a group performance is the result of averaging a number of possibilities. That is, group norms may be the result of confounding performances and the ordering of subjects in terms of them will be a function of this confounding. This became clear in the results obtained from some of our subjects who did not agree closely to what was expected from them in terms of our previous knowledge of their problem solving ability. The detailed analysis of processes revealed that our best problem solvers follow sequences characterized by a successful elimination of unnecessary questions as well as irrelevant details. In group norms these features will tend to be, as it were, dampened, in the performance of other subjects who also contribute to the definition of the norms.

At the present time problems are being prepared around strictly

defined schema in which the logical order of the questions that are sufficient and necessary to solve the problems can be known beforehand. These logical schema can be developed to deal with basic logical relations, definitions and functions, and the same schema can be used to build problems in which the presentation can be controlled by the experimenter.

The schema may be of varied complexity and the presentation can be made either precise or unstructured. The possibility that schema may be prepared by using electronic computers is being contemplated. The computer may be instructed to deal with a specific set of logical relations and produce a large number of schema that will in essence depend on these originally defined relations and on the operations that are introduced at predefined steps. A library of schema can thus be obtained and these could be used to prepare the actual problems. That is, we shall define the complexity of the problem in terms of the original set of logical relations and in terms of the context in which these are set.

For the study of variations and development of problem solving through age this may be a highly convenient point of departure. This we shall attempt to do in the future.

In terms of our previous discussion of scoring procedures this new development will not alter the basic rationale, but will change the way in which utility indexes and the values corresponding to the selection of a question at a given order will be computed. Further, since convex sets can be prepared in terms of a variety of hypotheses, each tactic (tactic being the sequence followed by a subject) can be analyzed in great detail. In this report we have only analyzed the observed

performance (in terms of group norms) and in terms of the hypothesis previously described.

It is expected that this approach will eliminate in part the subjectivity of other approximations to the study of problem solving and will permit the evaluation of talent in terms of both group and logically defined norms.

D. Interpretation of the Ellipsoids, Performance Curves and Convex Sets

Figures 1 to 3 represent the ellipsoids of the corresponding problems. From these figures and from the values of the respective ratios it is clear that in terms of the ambiguity of the questions, as judged by the experimental group, the problems can be ordered, from less to more ambiguous as follows: V, III, I, IV, and II. In the present report we shall analyze in detail only the performance of our sample of subjects and of each subject in problem V, such as indicated by observation of the ellipsoid to the parallelogram. This problem is the one in which there is a sharper differentiation between the questions that it is possible to ask. A similar analysis to the one that follows was also performed for the remaining problems.

The necessary and sufficient conditions for the solution of problem V is the information given in questions 1, 6, 7, 8, and 9. This set of questions should be used for the purposes of scoring in terms of a "best" solution. In the present study this was not the one used, instead we used the performance of the whole sample for norms. It is then with reference to the whole sample that the following discussion should be interpreted.

In Figure 13 the observed and the observed minus expected performance curves for each one of the fifteen subjects who solved the test are presented. For the separate values we used the distribution obtained by assuming that a question may appear in any order in the sequence and that the sequence of questions may have any length.

The whole line in Figure 13 means observed performance and the broken lines (O-E). The distance between the O and (O-E) curves is an indication of how far each subject at each step in the solution of the problem differs from the E distribution obtained using the assumptions already stated. That is, the subject who performs more randomly will approximate the zero line more closely than a subject who follows a definite plan. As a matter of fact the E distribution used in this discussion assumes that any question may be asked in any order. But if at a certain point in the sequence a question is asked and the value departs from the E value, then the O-E curve will raise. In summary, plateaux in the O-E curve indicate performance at the "random" level. Portions of this (O-E) curve with negative slope indicate that at that moment the subject accumulates less than what would be expected in terms of the E values. For instance, subject thirteen only departed in any noticeable degree from the E performance with the first question (question number one) and after his sixth question (question number nine), but the remaining part of his O-E curve shows a procedure that is for all practical purposes the one expected in terms of combinatorial theory. Nevertheless his O performance curve increases steadily. This is expected because of the way in which the values in Table 18 were computed. As a

matter of fact a subject that asks all possible questions has a better chance of showing a higher observed performance curve. Subject five (Figure 13) also shows a plateau corresponding to the last two questions asked and subjects two, three, six, eight, twelve, fourteen and fifteen show different plateaux at different time in their performance. Notice that subjects one, four, seven, nine, ten, and eleven show no plateaux and therefore their 0 and 0-E performance curves are close together. As a matter of fact the 0-E performance curve indicates what the performance is after eliminating the effects of the E values. Notice also that in some of the plateaux appear questions that we have listed as necessary and sufficient for the solution of the problem. Thus, the order in which questions are asked comes to be of crucial value in interpreting performance.

The effect of the order of questions is shown clearly by comparing the performance curves of subjects one and seven. Both asked for the same questions but in a different order. In both cases the (0-E) curves show a marked departure from the 0 line, but subject seven represents in general a curve that raised more steadily, for both the 0 and the 0-E performances. That is, the scoring system used here considers order as a crucial factor in interpreting performance. If the performance curves of these subjects are interpreted in terms of the content of the problems we can see that for subjects like number thirteen it is difficult to find a rationale justifying his tactic. On the other hand the performances of subjects one, seven, nine, and ten are clear and logically consistent, if our interpretation of the problem is accepted.

It also happens that subjects one, seven, nine and ten, in terms of other attempts to evaluate their ability, are at the very high level among all the members of the group.

If we compare performance and O-E performance curves with the successful solution of the problems (Table 1) we find that the latter may cover a variety of problem solving procedures, some of them logically consistent and others almost at a random level. This confirms our previous hypothesis that the final answer to a problem says little about the process followed for its solution.

It should be remembered that our previous discussion is based on the results of norms obtained from group performances. This will have a tendency to dampen the good performances and make the worse look better. For instance, if we had evaluated subjects thirteen and fifteen in terms of the "best" sequence, based on questions one, six, seven, eight, and nine only, the curves corresponding to both of them would have been lower while those of subjects seven, nine, and ten would have shown better performance than at present. This type of scoring will be attempted in the future. The previous discussion highlights the importance of developing a set of norms adequate to the purposes of our investigation. Thus, for instance, if we are interested in discovery of high talent and creativity, group norms and final answers may eliminate important individual differences in process.

The convex set for problem V is presented in Figure 7. Since the points here correspond to the accumulation of O, and of O-E values subjects having the same final solution will be represented by the same point. This happens to subjects four, seven, nine, and ten.

It is interesting to observe that the tactics of subjects four, seven, nine, ten, fifteen, three, and one will all include as the first two choices questions one and six, while subjects two and six do not, but include question nine in different order. As stated before questions one, six, and nine are among the necessary ones. By further analyzing the boundaries of this convex set it is found that the "best" performances are located in the upper right boundaries of the set. This probably means that the characterization of the corners of the convex set will serve to define the "maximum" and "minimum" points which in turn will probably correspond to best and worst performances. The "admissible" tactics will, in our case, be those located on the upper right boundary of the set. Also because of the properties of convex sets any point in the boundary or within the set can be expressed as a linear function of any two other points. This, of course, increases our possibility of objectively characterizing a subject's performances and of finding their equivalences and relationships.

For the same problem the convex set obtained by using 0th order, that is, questions not asked, is given in Figure 12. Notice that the tactics of subjects seven, nine and ten are located on the top right side corner in this figure, while the tactics of subject four that appeared together with the ones of subjects seven, nine, and ten in Figure 7 becomes in Figure 12 separated from them. By inspecting Figure 13 we see that the sequences of subject four are different from the ones of subjects seven, nine, and ten. That is, in the study of what subjects do and what they do not do, 0th order is essential for a better under-

standing of their processes. Other interesting points could be brought into our discussion, but we shall not attempt them here (25, 29).

If we had scored our subjects in terms of the "perfect" sequence the location of tactics in the corresponding sets might have been different and the points of maximum and minimum for both convex sets would have shown a different location, but still the two convex sets would be needed to interpret each subject's tactics.

In the present context we have used the E distribution based on combinatorial theory. But this expected distribution could have been developed for any theoretically or experimentally derived performance. Also instead of proportions, "bits" of information could have been used but this would not have changed the picture in any substantial way.

Chapter V

SUMMARY

Seventeen subjects were administered five problems in each experimental session. A continuous recording of cardiac rate was obtained by means of an electrocardiograph. Base lines in cardiac rate were determined for periods of five minute duration.

The study of the base lines has shown that as far as frequency of cardiac rate is concerned there is a decrement from the pre- to the post-testing values. Variability in successive periods of time is similar for both pre- and post-testing sessions.

Analyzing cardiac rate while the problems are being solved, it was found that though cardiac rates may vary for the same subject in different problems, the variability is constant, with the exception of a few subjects.

The implications that these findings may have in terms of tempo variables is detailed in the text.

The five problems used in this study have been analyzed by methods that consider number of questions asked by the subjects and their sequence. Subjects were scored in terms of group norms. An evaluation of the problems in terms of the experimental findings was made. Though all the problems were analyzed, in the present report for the sake of brevity we present only the findings obtained in Problem V. (See Appendix).

Ellipsoids, convex sets and performance curves are presented. These show that processes are highly personal and that attempting to interpret problem solving ability in terms of final answers is highly

misleading. Also it was found that the use of norms based on group performance may eliminate important individual differences. Suggestions for a solution of this problem are presented.

Discussion about hypotheses that may be used to interpret performance curves is given in the text. Individual tactics in approaching the solution of a problem may show interesting features when analyzed under various hypotheses as well as when they are considered not only from what subjects do but from what they do not do.

These preliminary findings have shown that it will be highly advisable to introduce other measures of autonomic functions and tempo. This we shall do in the immediate future. Also the possibility of developing new schema for our problems has emerged as compelling. This we will also do. It will allow us to grade problems in terms of their logical complexity and presentation. This will be of utmost help to compare performances in problem solving at different age levels, and will perhaps provide a way of exploring disturbances in complex mental processes under pathological conditions.

Chapter VI

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APPENDIX

Table 1

Correct and Incorrect Solutions to
Experimental Problems for 17 Subjects*

	Problems				
Subjects	I	II	III	IV	V
1	X	X	X	0	X
2	X	X	X	0	0
3	0	0	0	0	X
4	X	X	X	X	0
5	X	0	X	0	X
6	X	X	X	X	X
7	X	X	X	X	X
8	X	0	X	0	X
9	X	X	X	X	X
10	0	X	0	0	X
11	0	X	X	X	X
12	X	X	X	0	X
13	0	X	X	0	X
14	0	0	X	0	0
15	0	0	X	0	0
16	-	X	X	0	-
17	-	X	X	-	-

* Correct = X

Incorrect = 0

Incomplete = (-)

Table 2

Means, Sigmas, and Sigmas of the Means of
Heart Rate for Baselines One and Two

Subjects	Baseline I			Baseline II				$\frac{M_1-M_2}{\sigma \text{ diff } M}$
	M_1	σ_1	σ_{M_1}	M_2	σ_2	σ_{M_2}	M_1-M_2	
1	86.26	7.86	.975	85.43	8.63	1.070	.81	.56
2	77.18	4.06	.308	77.18	6.13	.760	.00	.00
3	112.66	7.54	.935	102.18	6.97	.864	10.48	8.24**
4	91.29	6.52	.808	90.28	5.73	.710	1.01	.94
5	75.38	7.26	.900	75.38	6.30	.781	.00	.00
6	91.49	8.21	1.018	71.15	6.44	.798	20.34	15.76**
7	79.80	8.85	1.097	92.11	7.91	.981	-12.31	-8.37**
8	85.65	7.01	.869	85.43	7.51	.931	2.22	1.74
9	89.08	8.96	1.111	90.69	7.39	.916	-1.61	-1.12
10	84.25	6.84	.848	76.98	6.44	.799	7.27	6.24**
11	76.58	5.75	.713	69.73	6.56	.813	6.85	6.34**
12	84.85	8.63	1.070	63.68	8.91	1.105	21.17	13.76**
13	86.26	6.39	.792	76.58	5.27	.653	9.68	9.43**
14	93.93	8.34	1.034	74.36	7.30	.905	19.57	14.24**
15	84.44	6.93	.859	78.40	6.64	.823	6.04	5.08**
16								
17	93.72	6.98	.864	77.18	6.13	.760	5.05	4.44**

** - Significant at the .01 level

(Heart Rate expressed in beats per minute)

Table 3

Ranges of Cardiac Rate for
Baselines One and Two

Subjects	B_1	B_2
1	22.92	29.47
2	6.55	19.65
3	16.38	19.65
4	22.93	13.10
5	16.37	16.38
6	19.65	13.10
7	26.20	19.65
8	13.10	19.65
9	22.92	16.37
10	13.10	19.65
11	13.10	22.92
12	26.20	22.93
13	9.82	13.10
14	19.65	19.65
15	16.38	16.38
16		
17	16.38	19.65
Mean	17.603	18.956

(Heart Rate expressed in beats per minute)

Table 4

Mean Cardiac Rate for
the Experimental Problems I, II, III, IV, and V

Subjects	I	II	III	IV	V
1	86.68	81.61	86.78	82.16	79.22
2	78.90	74.70	76.36	76.84	76.87
3	117.70	113.42	110.93	111.84	110.05
4	105.92	99.78	101.88	108.46	97.07
5	73.98	71.50	69.61	70.00	69.46
6	90.19	83.84	81.53	80.60	77.39
7	99.68	99.18	103.68	103.38	100.10
8	84.88	85.54	84.20	84.36	84.23
9			93.96		89.47
10	85.22	83.22	82.18	80.90	81.22
11	77.08	76.16	75.56	75.28	74.05
12	73.96	72.70	74.12	67.38	67.16
13	88.90	87.72	85.34	82.87	81.01
14	105.96	99.08	96.52	93.92	85.10
15	85.64	79.58	82.90	81.08	82.45
16					
17		90.57	94.32		

(Heart Rate expressed in beats per minute)

Table 5

Sigmas of Cardiac Rate for
Experimental Problems

Subjects	I	II	III	IV	V
1	7.44	6.99	6.78	7.36	6.97
2	5.66	6.48	5.78	6.68	6.40
3	7.34	6.88	9.32	6.53	8.64
4	7.60	8.35	9.20	7.58	7.50
5	6.89	7.00	6.28	6.77	6.40
6	10.07	6.78	5.46	5.12	6.22
7	9.20	7.94	9.52	8.32	8.60
8	6.48	7.88	5.95	5.45	7.33
9			7.52		8.72
10	6.70	9.98	7.12	6.02	6.24
11	5.59	5.55	6.24	6.27	6.59
12	8.10	7.14	10.09	7.62	6.10
13	6.88	6.28	6.80	6.92	6.44
14	9.06	6.90	8.45	8.88	8.34
15	7.08	6.84	6.70	6.86	6.90
16					
17		7.58	6.19		
Mean	7.44	7.24	7.34	6.88	7.16

(Heart Rate expressed in beats per minute)

Table 6

Ranges of Cardiac Rate for
the Experimental Problems I, II, III, IV, and V

Subjects	I	II	III	IV	V
1	22.92	22.92	19.65	19.65	26.20
2	16.37	13.10	13.10	16.37	16.37
3	19.65	22.93	26.20	13.10	36.03
4	26.20	16.37	36.02	19.65	26.20
5	22.93	19.65	16.37	22.93	19.65
6	16.37	16.38	8.55	13.10	22.92
7	29.47	22.92	32.75	22.93	22.93
8	26.20	22.93	13.10	22.92	22.93
9				16.38	26.20
10	13.10	16.37	16.38	13.10	13.10
11	26.20	13.10	19.65	13.10	13.10
12	22.92	19.65	29.47	22.92	29.47
13	26.20	19.65	13.10	26.20	26.20
14	29.47	16.37	22.93	25.48	22.93
15	19.65	19.65	19.65	19.65	19.65
16					
17		22.92	16.38		
Mean	22.689	18.994	20.220	19.165	29.253

(Heart Rate expressed in beats per minute)

Table 7

Significant Differences for Variances of Heart Rate for Base Lines and Problems*

Subjects	B_1, B_2	B_1, I	B_1, II	B_1, III	B_1, IV	B_1, V	B_2, I	B_2, II	B_2, III	B_2, IV	B_2, V	I, II	I, III	I, IV	I, V	II, III	II, IV	II, V	III, IV	III, V	IV, V
1	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0
2	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	-	0	-	-	0	-	+	0	0
4	0	0	0	-	0	0	-	-	-	0	-	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	+	+	+	-	0	0	0	0	+	+	+	+	0	+	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	+	+	0	0	0	-
9	0			0		0			0		0									0	
10	0	0	-	0	0	0	0	-	0	0	0	-	0	0	0	0	+	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	+	0	0	0	0	+	0	0	0	+	-	0	0	+	+	+
13	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16																					
17	0		0	0				0	0							0					

* See text

Table 8

Number of Cards Selected by Each Subject for Each Problem and Mean Number of Cards Selected by the Group for Each Problem

Subjects	Experimental Problems I	II	III	IV	V
1	14	5	9	9	5
2	21	7	7	7	10
3	8	0	7	5	11
4	10	5	7	9	5
5	21	4	7	8	9
6	14	4	8	6	7
7	14	4	5	6	5
8	10	5	8	4	6
9	13	6	9	9	5
10	12	3	10	11	5
11	13	5	4	8	6
12	13	3	6	10	8
13	10	3	5	12	9
14	8	2	7	10	10
15	12	6	8	11	11
16		7	6		
17		3	4		
Mean	12.86	4.94	6.88	8.33	7.46

Table 9

Utility Indexes for Questions for Experimental Problems

Questions	Experimental Problems I	II	III	IV	V
1	1.00	.00	.18	.86	1.00
2	.50	.12	.62	.86	.42
3	.81	.18	.18	.86	.42
4	1.00	.31	.81	.60	.50
5	.68	.31	.31	.33	.21
6	.56	.00	.00	.33	.92
7	.44	.12	.56	.13	1.00
8	.81	.06	.25	.66	.87
9	.12	.31	.88	.40	.92
10	.00	.44	.31	.40	.14
11	.31	.12	.12	1.00	.14
12	.62	.18	.38	.73	.00
13	.44	.31	.81	.73	.14
14	.12	.00	.00		.28
15	.25	.18	.06		
16	.18	.50	.06		
17	.18	.12	.56		
18	.00	.25	.25		
19	.56	.50	.00		
20	.62		.00		
21	.12				
22	.18				
23	.31				
24	.25				
25	.62				
26	.50				
27	.50				
28	.06				
29	.50				

Table 10

Problem I

Observed Proportions of Questions Asked or Not Asked in Each Order

Order	Questions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0284					0020					0020				
2	0020	0061	0061		0020		0020	0142							
3	0020		0102		0061		0040	0020							
4		0040	0102	0061	0040		0020					0020			0020
5				0081	0040			0020				0040	0020		0020
6	0020	0020		0040	0020	0061		0020							
7				0040	0020		0040	0020				0061			
8		0020		0020		0020	0040	0020			0020	0020	0020		
9				0020	0020	0020			0040		0040				0020
10		0020		0020		0020		0020		0020			0020		0020
11		0020	0020	0020		0020					0040	0061			
12				0020				0020	0020				0020		0020
13						0040						0020	0040	0040	
14													0020		
15															
16															
17															
18				0020	0020								0020		
19														0020	
20															
21															
Sum	0344	0181	0285	0342	0241	0201	0160	0282	0060	0020	0120	0222	0160	0060	0100
Zero	0	0162	0061	0	0102	0142	0183	0061	0284	0325	0223	0122	0183	0284	0244

Table 10
(Cont.)

Problem I

Observed Proportions of Questions Asked or Not Asked in Each Order

Order	Questions 16	17	18	19	20	21	22	23	24	25	26	27	28	29	Sum
1				0020											
2				0020											
3				0081	0020										
4					0020							0020			
5	0020				0040	0040				0020					
6		0020		0020	0020		0061					0040			
7	0020			0020	0020			0020		0020	0040	0020			
8				0020	0020			0040	0020			0061			
9					0020			0040	0020	0040		0020			
10					0020				0040	0040	0040			0020	
11										0040	0020				
12	0020	0020									0040		0020	0040	
13					0020								0020	0020	
14					0020					0020		0020		0040	
15				0020						0020	0020				
16						0020					0020			0020	
17	0020							0020						0020	
18		0020							0020						
19														0020	
20							0020								
21		0020								0020					
Sum	0080	0080	0	0201	0220	0060	0081	0120	0100	0220	0180	0180	0040	0180	4521
Zero	0264	0264	0345	0142	0122	0284	0264	0225	0244	0122	0162	0162	0304	0162	5440

Table 11

Problem I

Observed Minus Expected Proportions of Questions Asked or Not Asked in Each Order

Order	Questions														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0272					0008					0008				
2	0008	0049	0049		0008		0008	0130							
3	0008		0090		0049		0028	0008							
4		0028	0090	0049	0028		0008					0008			0008
5				0069	0028			0008				0028	0008		0008
6	0008	0008		0028	0008	0049		0008							
7				0028	0008		0028	0008				0049			
8		0008		0008		0008	0028	0008			0008	0008	0008		
9				0008	0008	0008			0028		0028				0008
10		0008		0008		0008		0008		0008			0008		0008
11		0008	0008	0008		0008					0028	0049			
12				0008				0008	0008				0008		0008
13						0028						0008	0028	0028	
14													0008		
15															
16															
17															
18				0008											
19					0008								0008		
20														0008	
21															
Sum	0296	0109	0237	0222	0145	0117	0100	0186	0036	0008	0072	0150	0076	0036	0040
Zero	-0012	0150	0049	-0012	0090	0130	0171	0049	0272	0313	0211	0110	0171	0272	0232

Table 11
(Cont.)

Problem 1

Observed Minus Expected Proportions of Questions Asked or Not Asked in Each Order

Order	Questions													
	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1				0008										
2				0008										
3				0069	0008									
4					0008							0008		
5	0008				0028	0028				0008				
6		0008		0008	0008		0049					0028		
7	0008			0008	0008			0008		0008	0028	0008		
8				0008	0008			0028	0008			0049		
9					0008			0028	0008	0028		0008		
10					0008				0028	0028	0028			0008
11										0028	0008			
12	0008	0008									0028		0008	0028
13					0008								0008	0008
14					0008					0008		0008		0028
15				0008						0008	0008			
16						0008					0008			0008
17	0008							0008						0008
18		0008							0008					
19														0008
20							0008							
21		0008								0008				
Sum	0032	0032	0	0117	0100	0036	0057	0072	0052	0124	0108	0109	0016	0096
Zero	0252	0254	0313	0130	0110	0272	0252	0211	0252	0110	0150	0150	0292	0150

Table 12

Problem II

Observed Proportion of Questions Asked or Not Asked in Each Order

Order	Questions																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum
1				0031	0031	0031					0031	0062	0124			0062	0093		0062	
2				0031	0093		0062		0093			0031	0031		0062	0062		0031	0031	
3		0031	0031	0031				0062	0031	0062			0031		0031	0031			0154	
4	0031		0031	0031					0062	0031	0062			0031		0031		0093	0031	
5			0062	0062	0031					0093					0031	0031		0031		
6		0062								0031		0031				0031				
7					0031					0031						0031				
8							0031													
9																				
10																				
Sum	0031	0093	0124	0186	0186	0031	0093	0062	0186	0248	0093	0124	0186	0031	0124	0278	0093	0155	0278	2802
Zero	0494	0493	0402	0340	0340	0494	0433	0464	0340	0278	0433	0402	0340	0494	0402	0247	0433	0371	0247	7616

Table 13

Problem 22

Observed Minus Expected Proportions of Questions Asked or Not Asked in Each Order

Order	Questions																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Sum
1				.0003	.0003	.0003					.0003	.0034	.0034			.0034	.0068		.0034	
2				.0003	.0068		.0034		.0068			.0003	.0003		.0034	.0034		.0303	.0003	
3		.0003	.0003	.0003				.0034	.0003	.0034			.0003		.0003	.0003			.1136	
4	.0003		.0003	.0003					.0034	.0003	.0034			.0003		.0003		.0303	.0003	
5			.0034	.0034	.0068					.0068					.0003	.0035		.0303		
6		.0034								.0003		.0003				.0035				
7					.0003					.0003						.0068				
8							.0003													
9																				
10																				
Sum	.0003	.0137	.0040	.0046	.0074	.0003	.0037	.0034	.0102	.0108	.0037	.0040	.0302	.0035	.0040	.0085	.0065	.0374	.0166	
Zero	.0466	.0405	.0374	.0312	.0312	.0466	.0405	.0436	.0312	.0250	.0405	.0374	.0312	.0466	.0374	.0219	.0405	.0343	.0219	

Table 14

Problem III

Observed Proportions of Questions Asked or Not Asked in Each Order

Order	Questions																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum
1		0206					0029		0176				0029				0059				
2		0029		0029			0147		0235								0059				
3		0059			0059		0029			0059		0029	0235		0029						
4	0059		0059	0147						0059	0029		0088					0059			
5			0029	0118	0088			0059				0029	0029		0029	0029	0029				
6				0059	0029		0059	0029	0029	0029		0059	0029				0029	0029			
7	0059	0029		0029				0059		0029	0029	0059					0029	0029			
8											0029					0029	0088	0029			
9			0029	0029								0029									
10							0029														
11																					
Sum	0118	0323	0117	0411	0176	0	0293	0147	0440	0176	0087	0205	0410	0	0058	0058	0293	0146	0	0	3458
Zero	0382	0176	0382	0088	0323	0500	0206	0353	0059	0323	0412	0294	0088	0500	0441	0441	0206	0353	0500	0500	6527

Table 13

Problem III

Observed Minus Expected Proportions of Questions Asked or Not Asked in Each Order

Order	Questions 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		.0181					.0004		.0151				.0004				.0034			
2		.0004		.0004			.0122		.0210								.0034			
3		.0034			.0034		.0004			.0034		.0004	.0210		.0004					
4	.0034		.0034	.0122						.0034	.0004		.0063					.0034		
5			.0004	.0093	.0063			.0034				.0004	.0004		.0004	.0004	.0004			
6				.0034	.0004		.0034	.0004	.0004	.0004		.0034	.0004				.0004	.0034		
7	.0034	.0004		.0004				.0034		.0004	.0004	.0034					.0004	.0034		
8											.0004					.0004	.0063	.0004		
9			.0004	.0004								.0004								
10							.0004													
11																				
Sum	.0064	.0223	.0042	.0261	.0101	0	.0168	.0072	.0365	.0376	.0032	.0080	.0283	0	.0008	.0008	.0143	.0046	0	0
Zero	.0357	.0151	.0357	.0063	.0298	.0475	.0181	.0339	.0034	.0298	.0187	.0269	.0063	.0475	.0416	.0416	.0181	.0338	.0475	.0475

Table 16

Problem IV

Observed Proportion of Questions Asked or Not Asked in Each Order

Order	Questions													
	1	2	3	4	5	6	7	8	9	10	11	12	13	%
1	014							048			014			14
2	019	010		005			005		029	005	005			
3	005	010	010		005					019	019	010		
4	005	010	010	019		005	005			005	010	010		
5	005	014	024	010	010	005		005			005		019	
6	005	005		005	010	043				005	005	005		43
7	005	005	005	005		043					014	010	005	
8		005	005	005	005				005			019	010	
9	005					005					005		019	
10	005	005	005			005	005					005		
11		005	005										005	
12			005											
13														
Sum	068	069	069	049	030	030	015	053	034	034	077	039	038	
Zero	010	010	010	029	048	048	063	024	043	043	0	019	019	

Table 17

Problem IV

Observed Minus Expected Proportions of Questions Asked or Not Asked in Each Order

Order	Questions												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	.0091							.0421			.0231		
2	.0131	.0241		.0069			-.0009		.0231	-.0091	-.0091		
3	-.0039	.0041	.0041		-.0039					.0131	.0131	.0041	
4	-.0039	.0091	.0091	.0131		-.0091	-.0709			-.0091	.0241	.0041	
5	-.0129	.0041	.0091	.0341	.0041	-.0291		-.0039			-.0039		.0131
6	-.0091	-.0091		-.0091	.0041	-.0491				-.0091	-.0391	-.0391	
7	-.0039	-.0091	-.0091	-.0091		-.0039					.0041	.0041	-.0039
8		-.0091	-.0091	-.0091	-.0091				-.0039			.0131	.0141
9	-.0091					-.0091					-.0391		.0131
10	-.0091	-.0091	-.0091			-.0091	.0704					-.0091	
11		-.0041	-.0041										-.0704
12			.0006										
13													
Sum	.0150	.0165	.0239	.0136	.0064	-.0055	-.0022	.0412	.0222	.0104	.0298	.0237	.0290
Zero	.0041	.0041	.0041	.0231	.0421	.0421	.0371	.0181	.0371	.0371	-.0159	.0131	.0131

Table 10

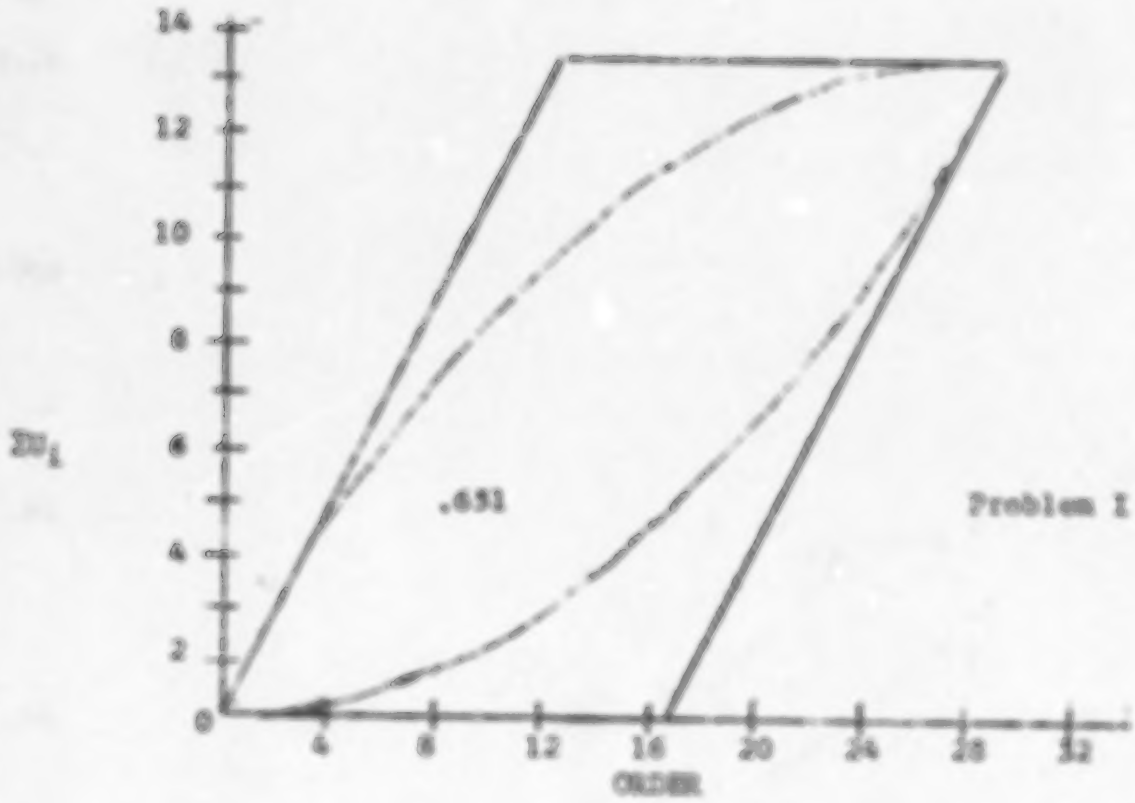
Problem V

Observed Proportions of Questions Asked or Not Asked in Each Order

Order	Questions													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0571			0048		0048			0048					
2		0048				0381	0048		0143	0048			0048	
3		0095	0048		0048		0333		0095					0095
4	0095	0048	0143	0048			0143	0143			0048			0048
5	0048		0095	0190			0048	0095	0190					0048
6						0095	0143	0095	0095				0048	
7			0048			0048		0238						0048
8		0095			0048	0048		0048	0048	0048				
9				0095				0048		0048	0048		0048	
10		0048				0048			0048		0048			
11					0095									
12														
13														
14														
Sum	0714	0334	0334	0381	0191	0668	0715	0667	0667	0144	0144	00	0144	0239
Zero	00	0380	0380	0333	0523	0046	00	0047	0047	0570	0570	0714	0570	0475

Table 19
Problem V
Observed Minus Expected Proportions of Questions Asked or Not Asked in Each Order

	Questions													
Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0520			-0005		-0003			-0003					
2	-0051	-0005				0330	-0075		0092	-0003			-0003	
3	-0051	0044	-0033		-0025		0192		0044					0044
4	0044	-0003	0022	-0003			0092	0092			-0003			-0003
5	-0005		0344	0139			-0005	0044	0139					-0003
6	-0051					0044	0092	0044	0044				-0003	
7	-0051		-0005			-0003		0187						-0003
8	-0051	0044			-0025	-0003		-0025	-0003	-0003				
9	-0051			0044				-0003		-0003	-0003		-0003	
10	-0051	-0003				-0003			-0003		-0003			
11	-0050				0045									
12	-0047													
13	-0038													
14	-0019													
Sum	0050	0079	0120	0177	0039	0262	0460	0364	0210	-0039	-0079	0	-0009	0035
Zero	-0050	0350	0350	0283	0473	-0004	-0050	-0025	-0003	0520	0520	0464	0520	0435



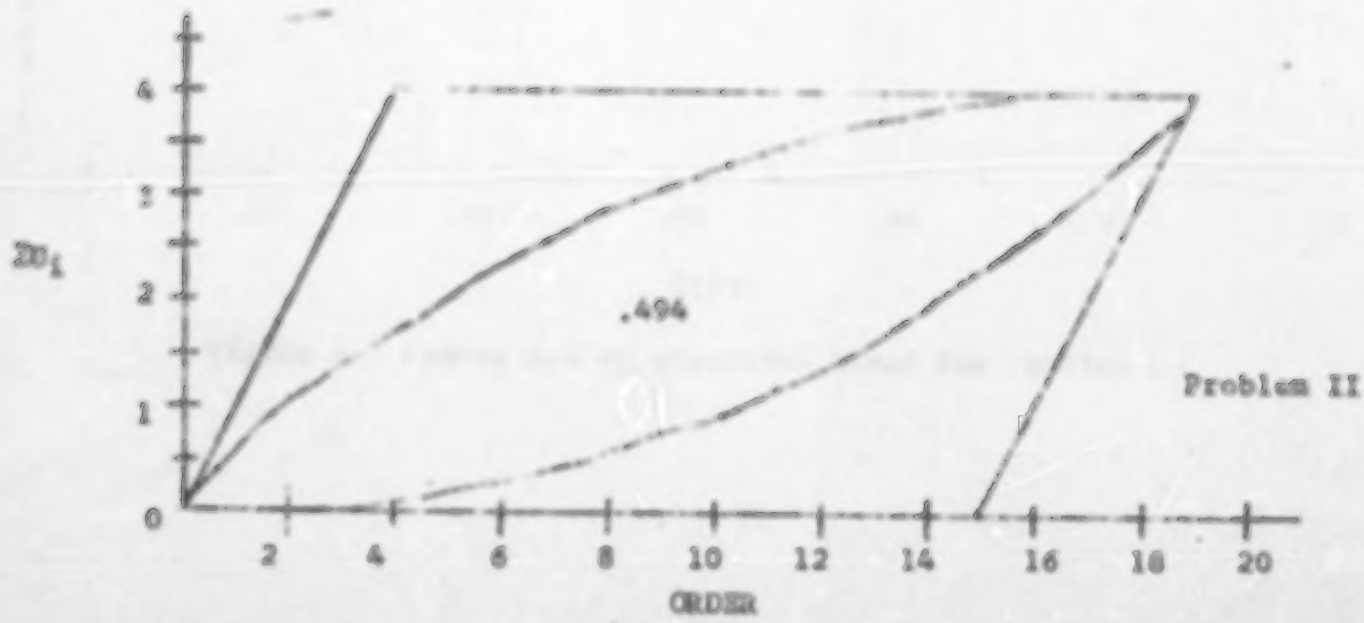


Figure 1. Ellipsoids and corresponding Parallelograms generated by performances of subjects on problems I and II and values of ratios.

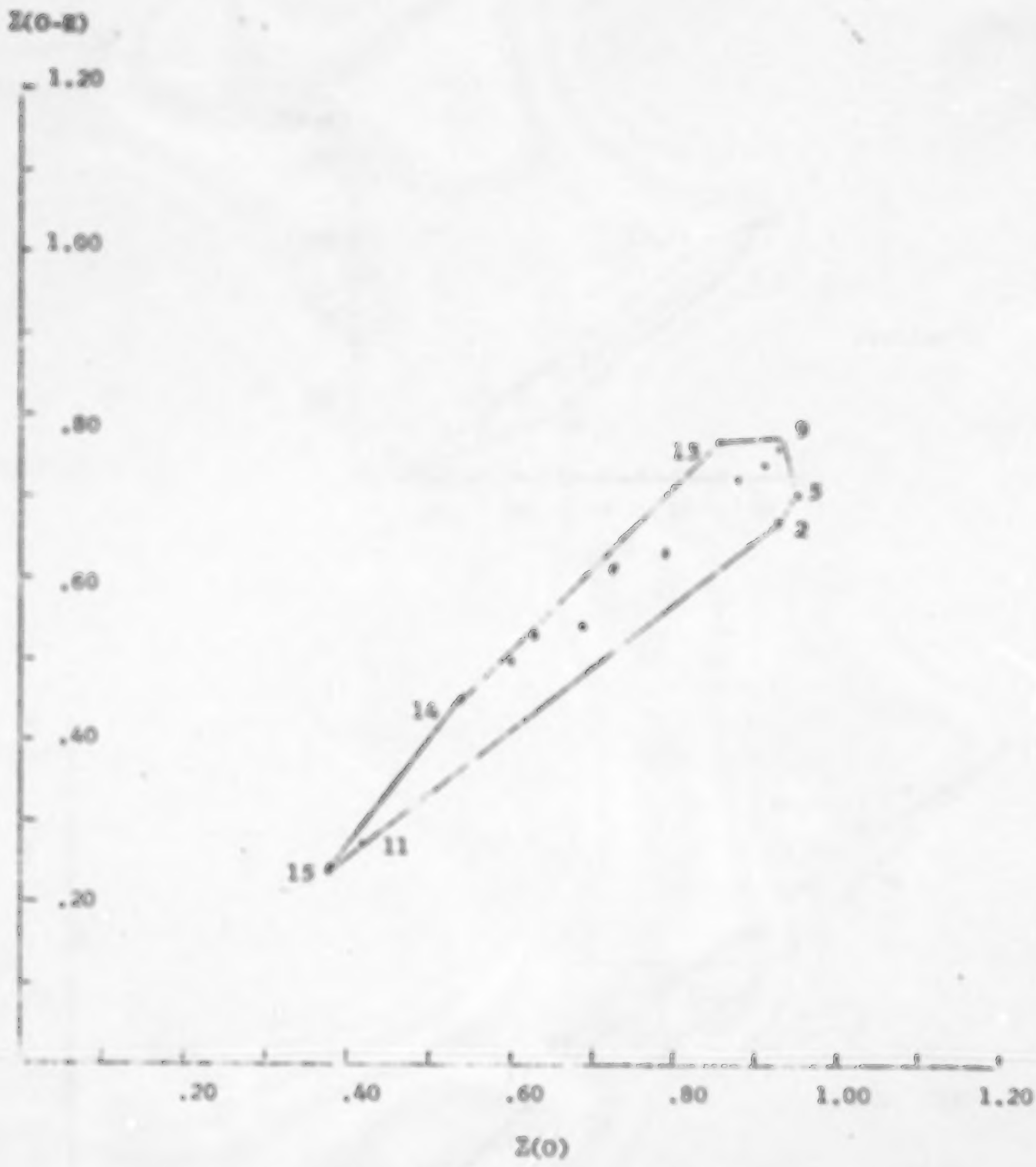
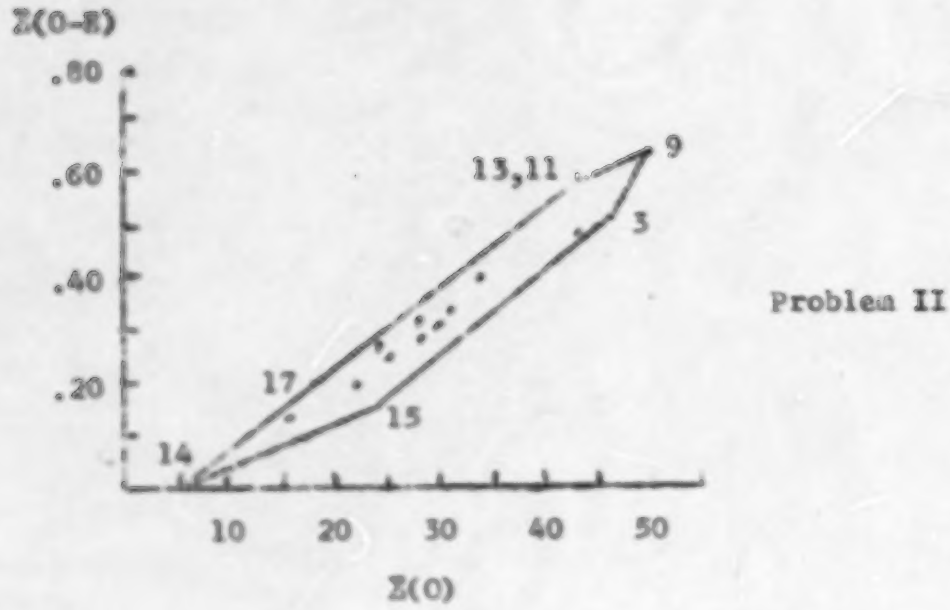
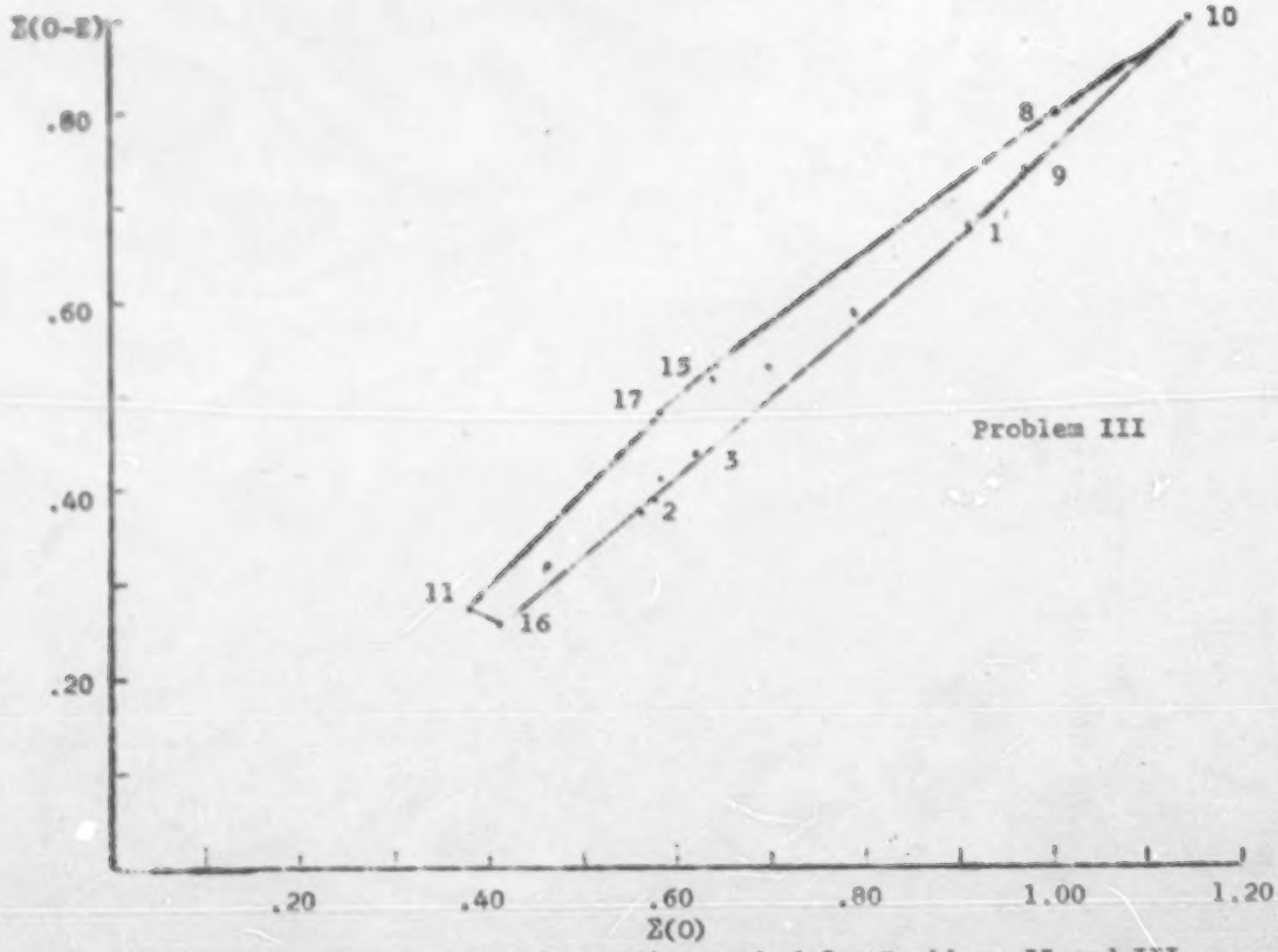


Figure 4. Convex set of questions asked for Problem I.



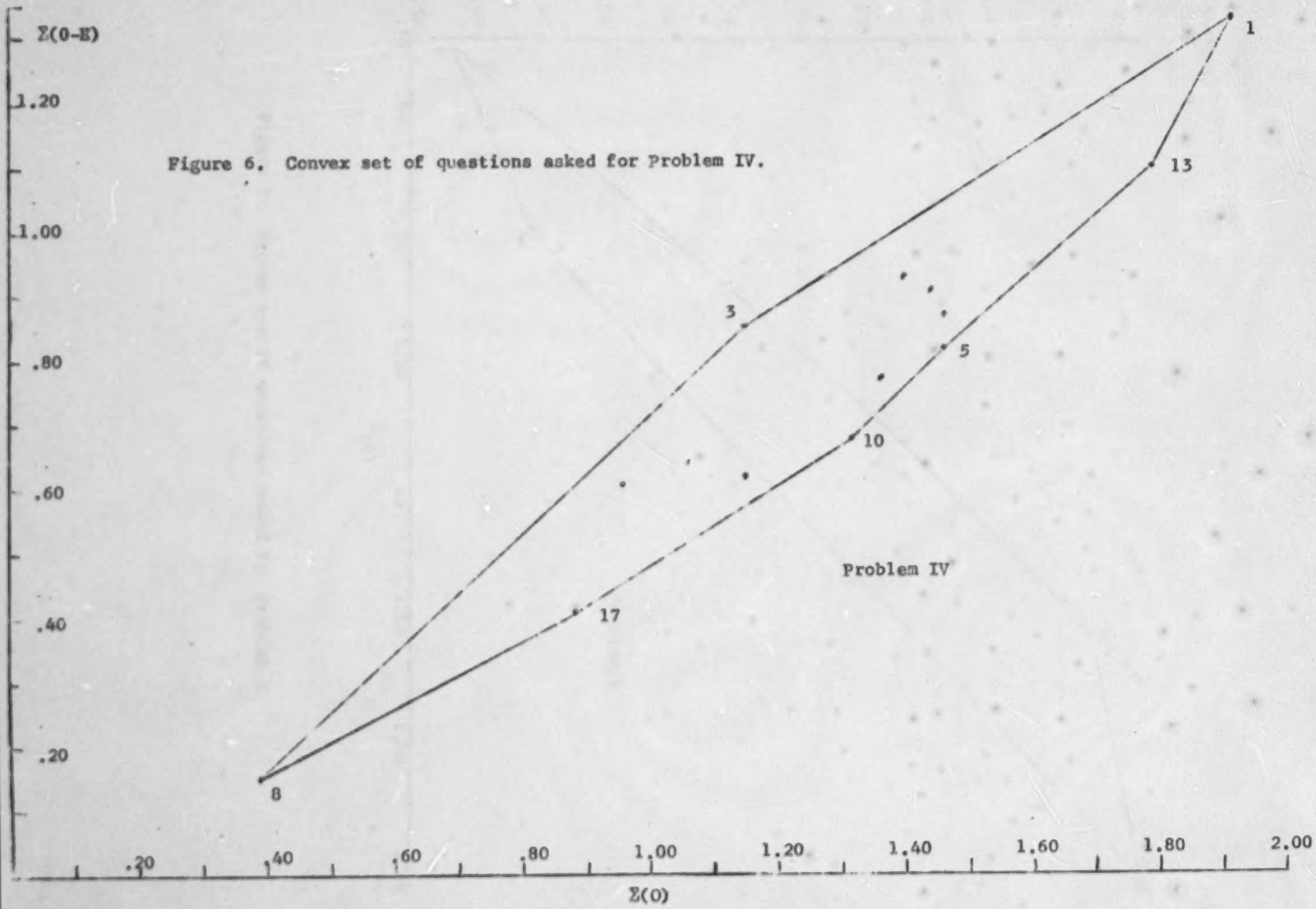
Problem II



Problem III

Figure 5. Convex sets of questions asked for Problems II and III.

Figure 6. Convex set of questions asked for Problem IV.



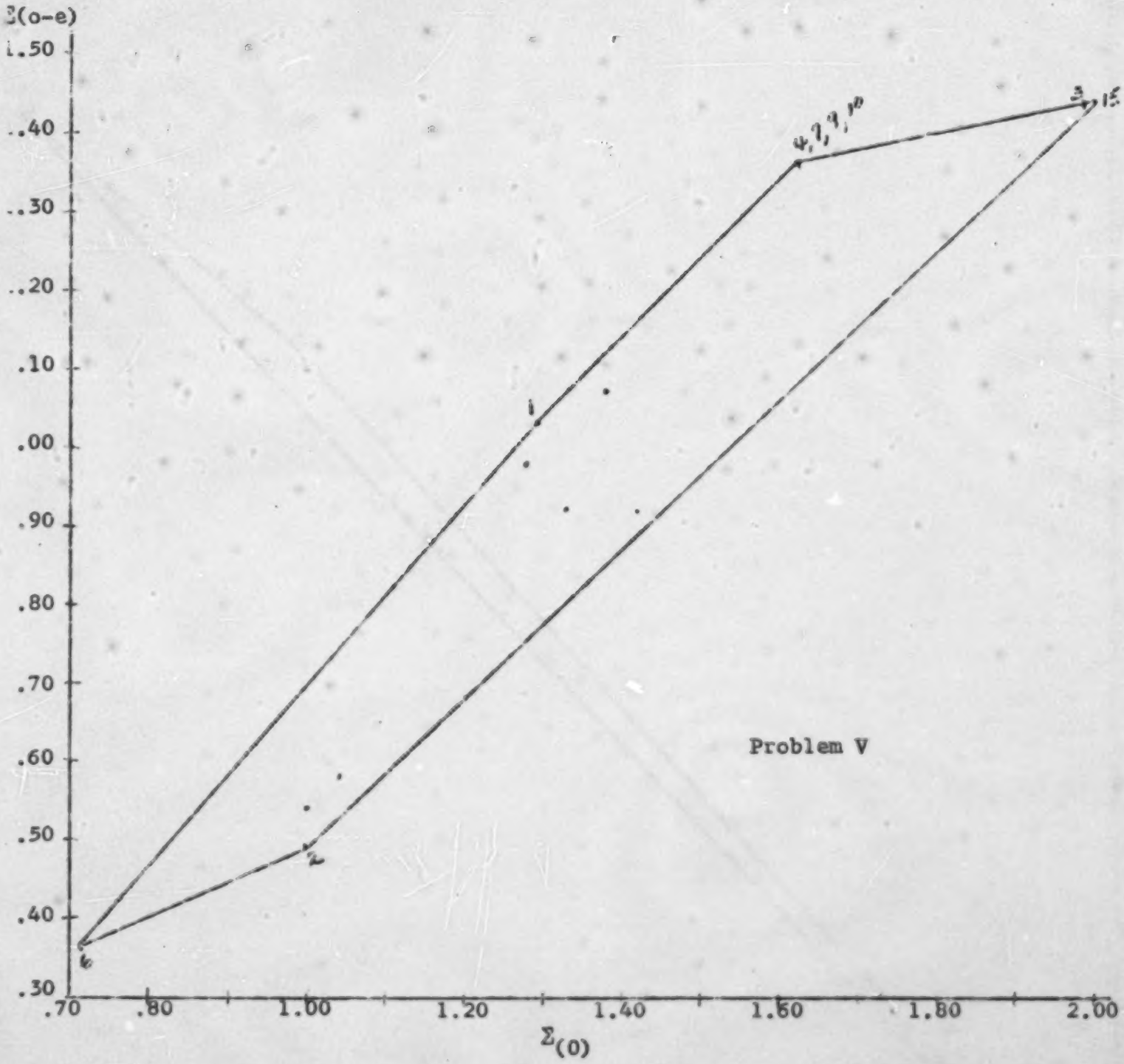


Figure 7. Convex set of questions asked for problem V.

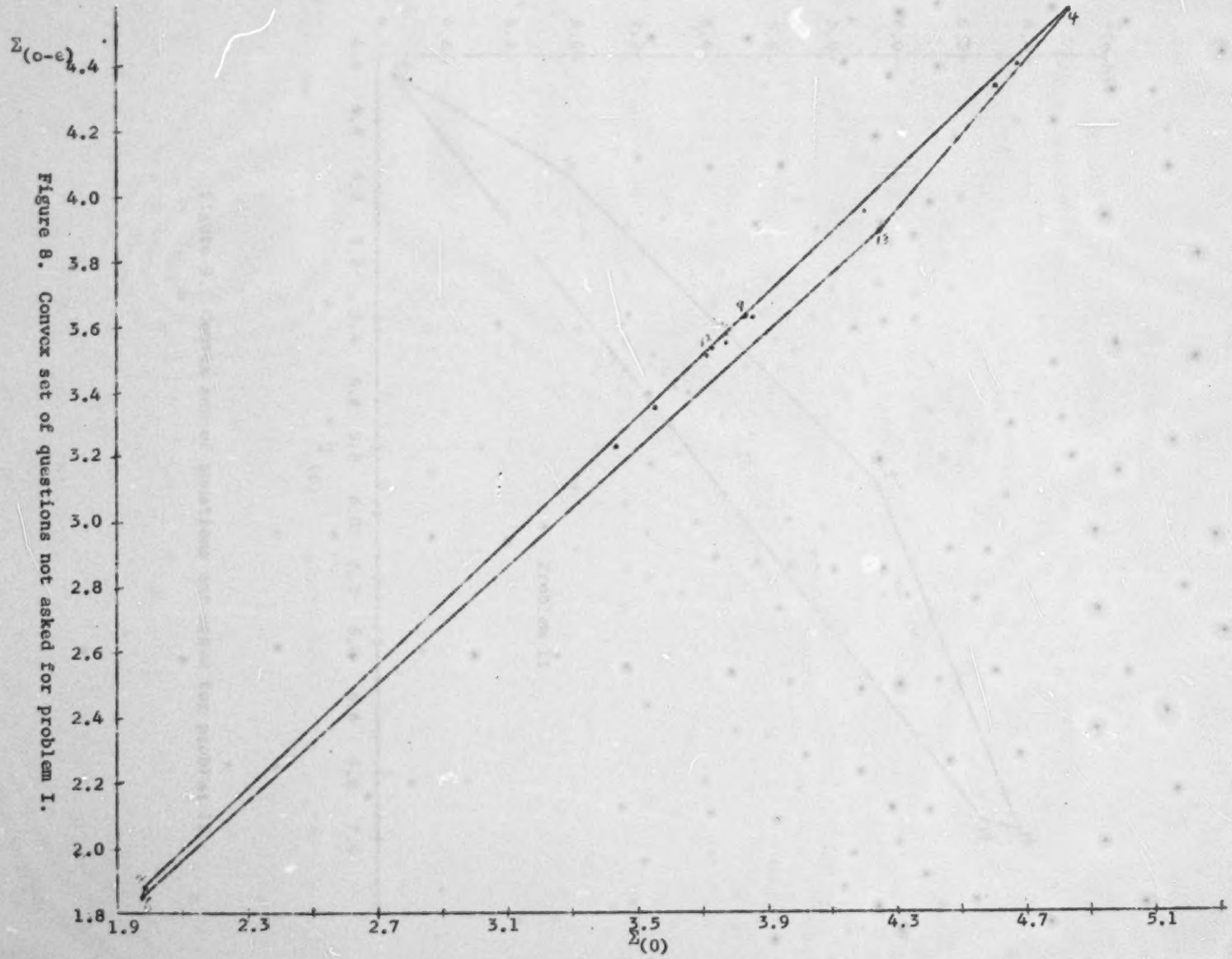


Figure 8. Convex set of questions not asked for problem I.

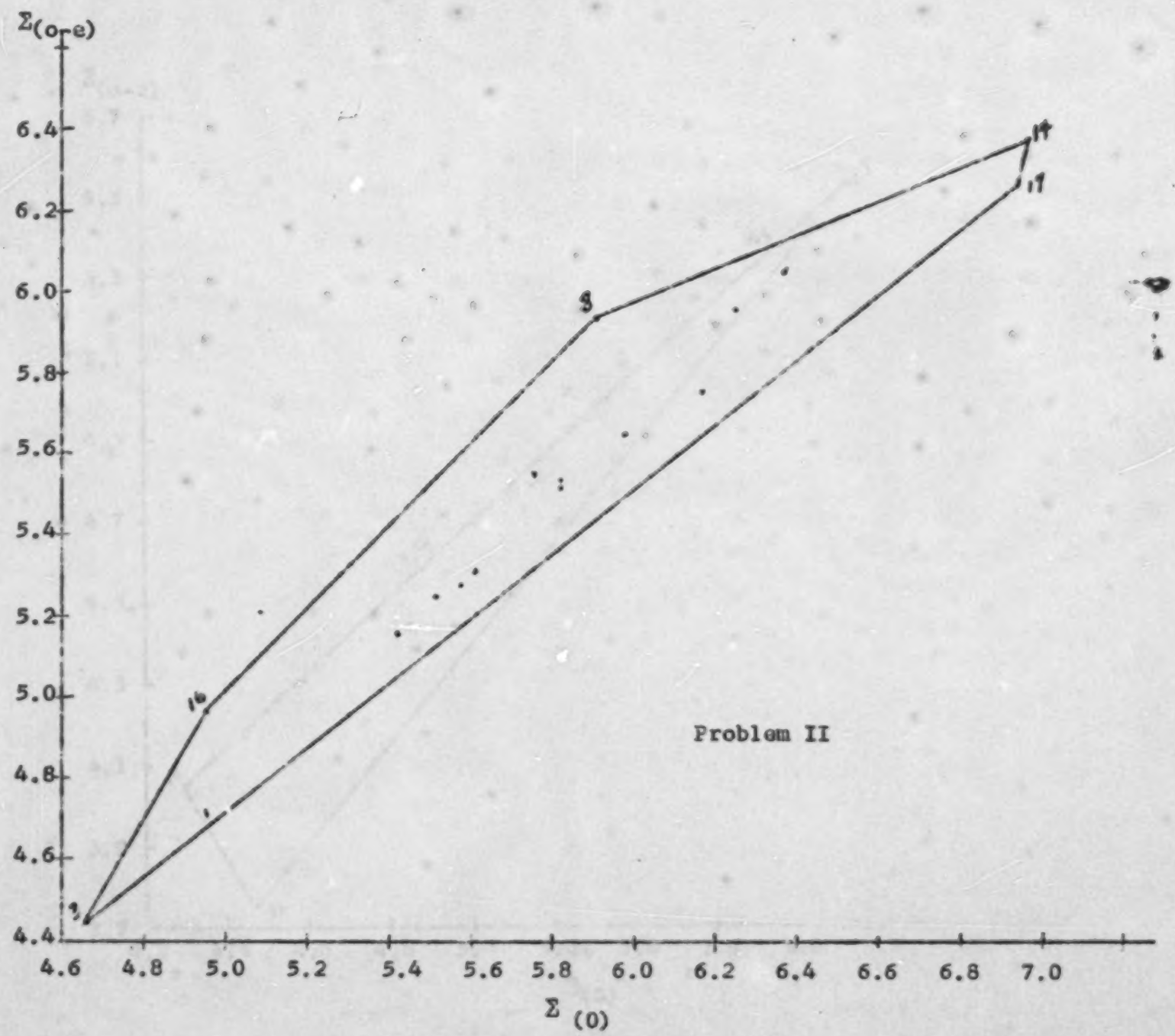


Figure 9. Convex set of questions not asked for problem II.

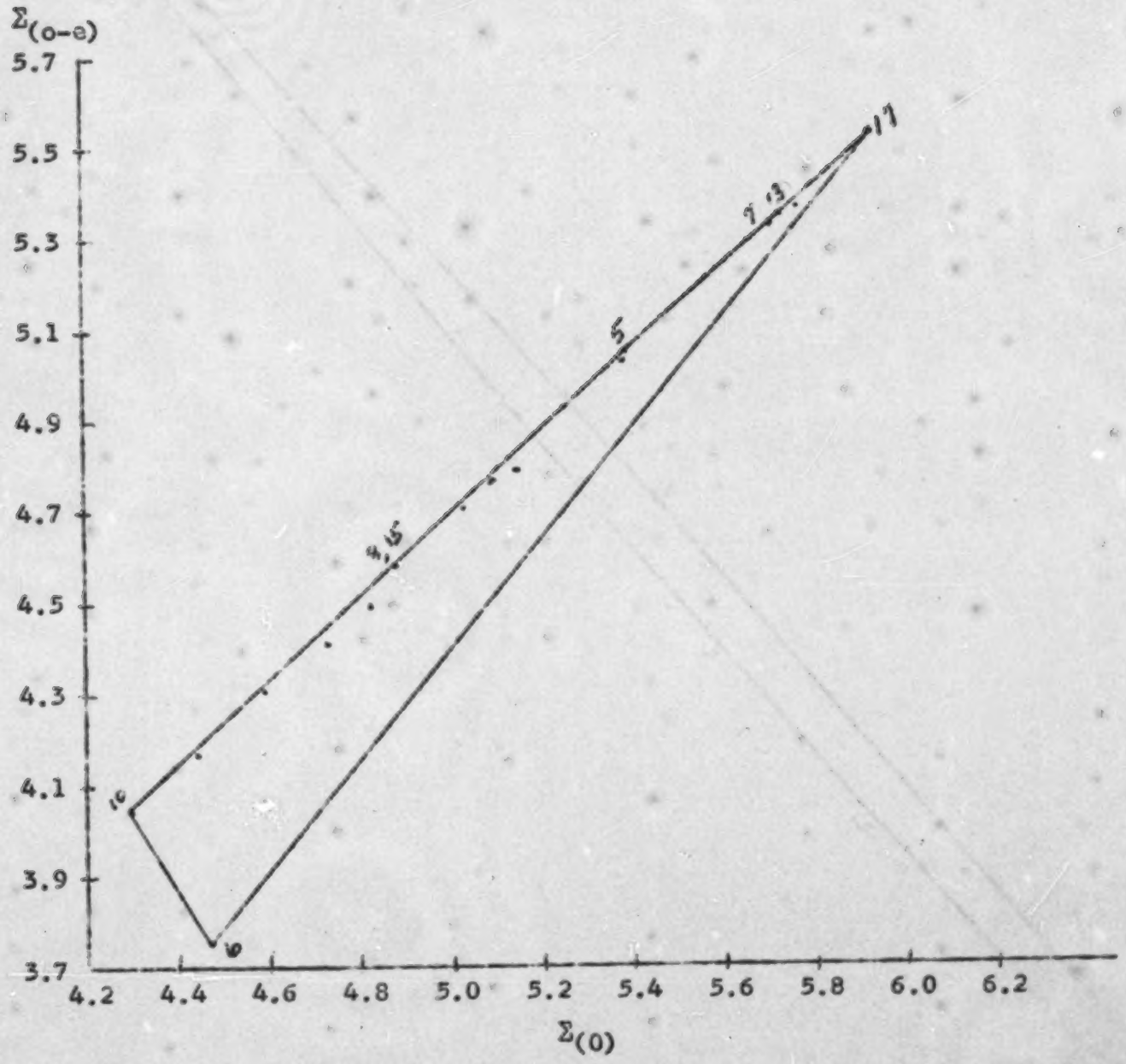


Figure 10. Convex set of questions not asked for problem III.

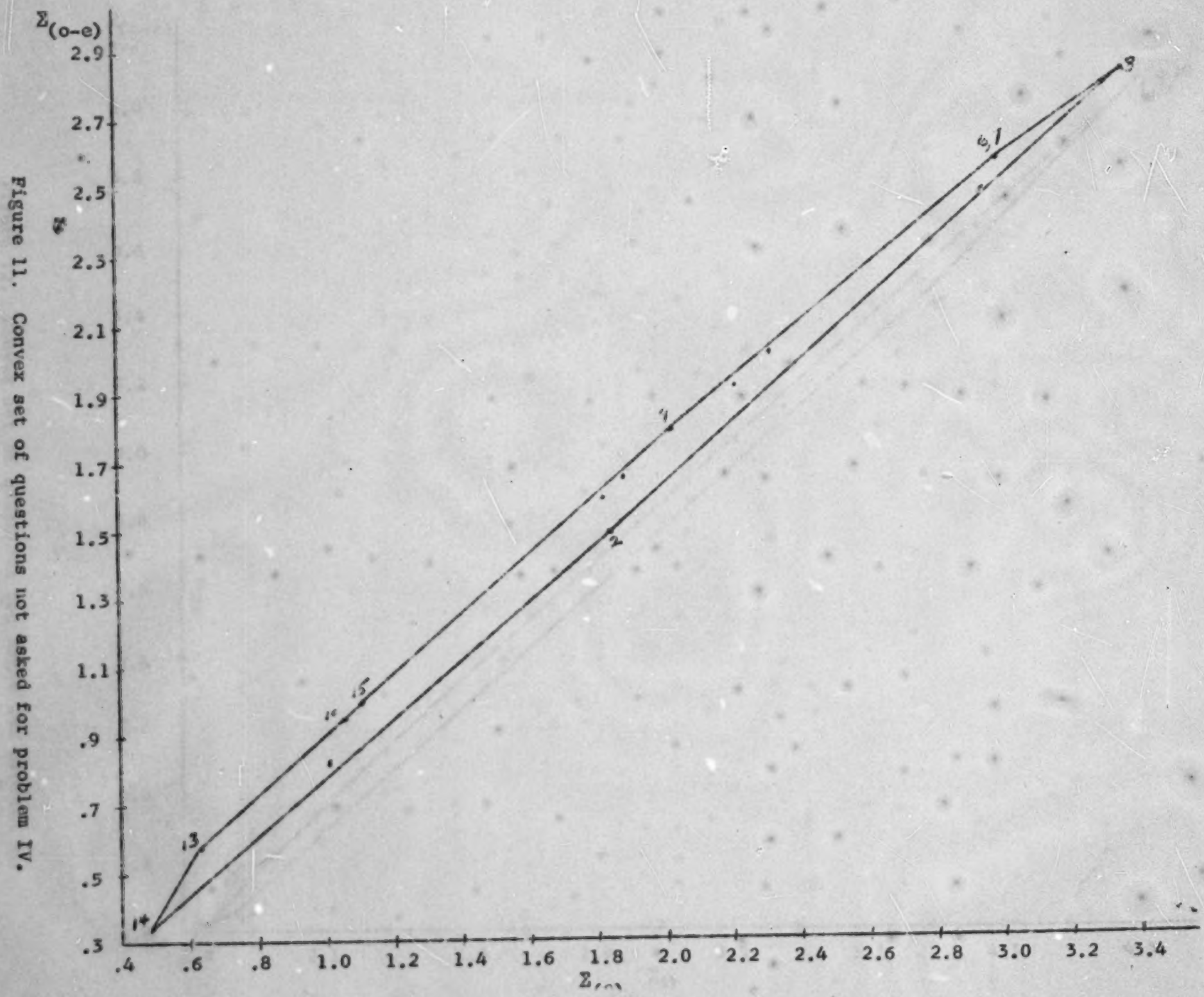


Figure 11. Convex set of questions not asked for problem IV.

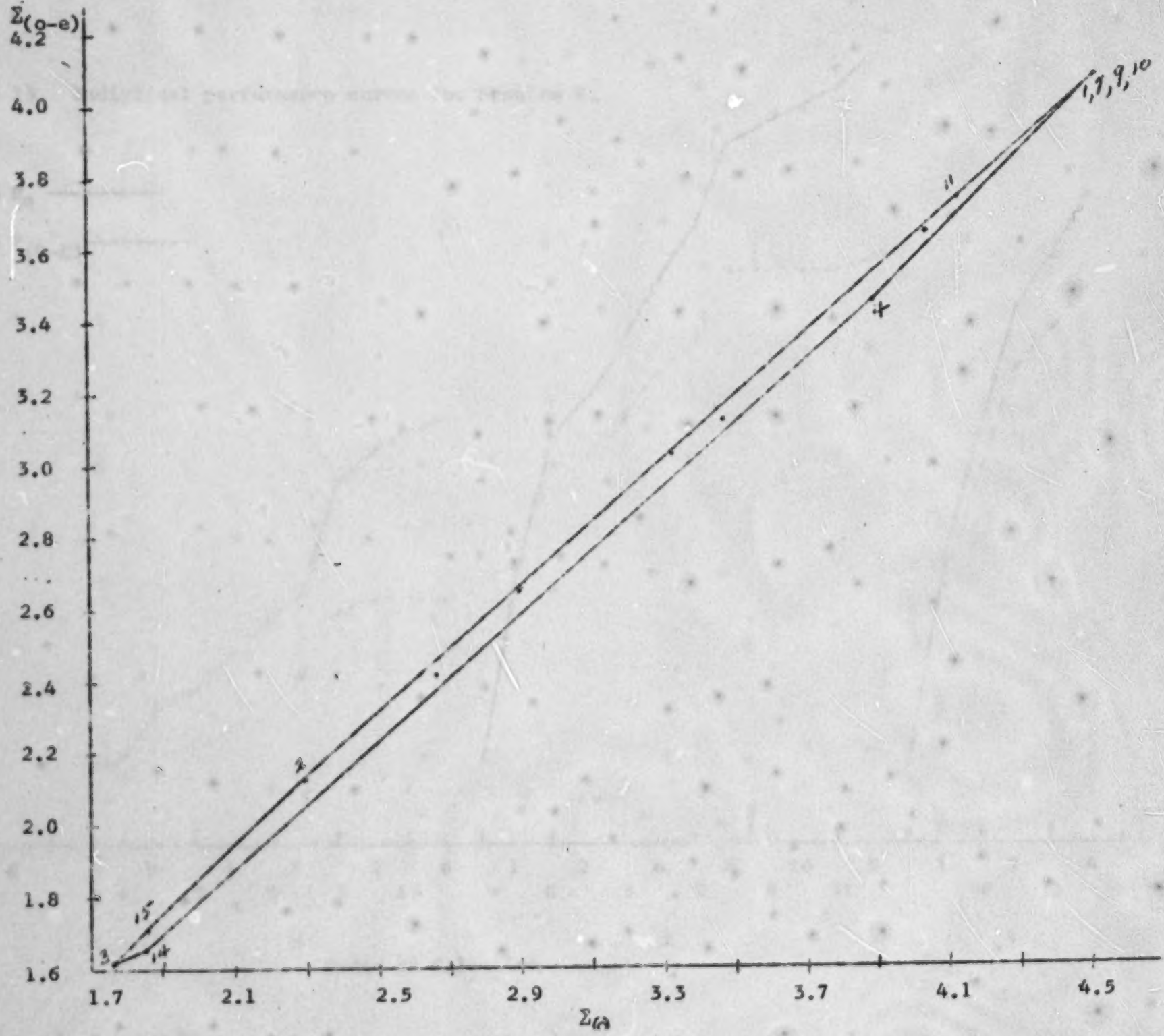


Figure 12. Convex set of questions not asked for problem V.

Figure 13. Individual performance curves for Problem V.

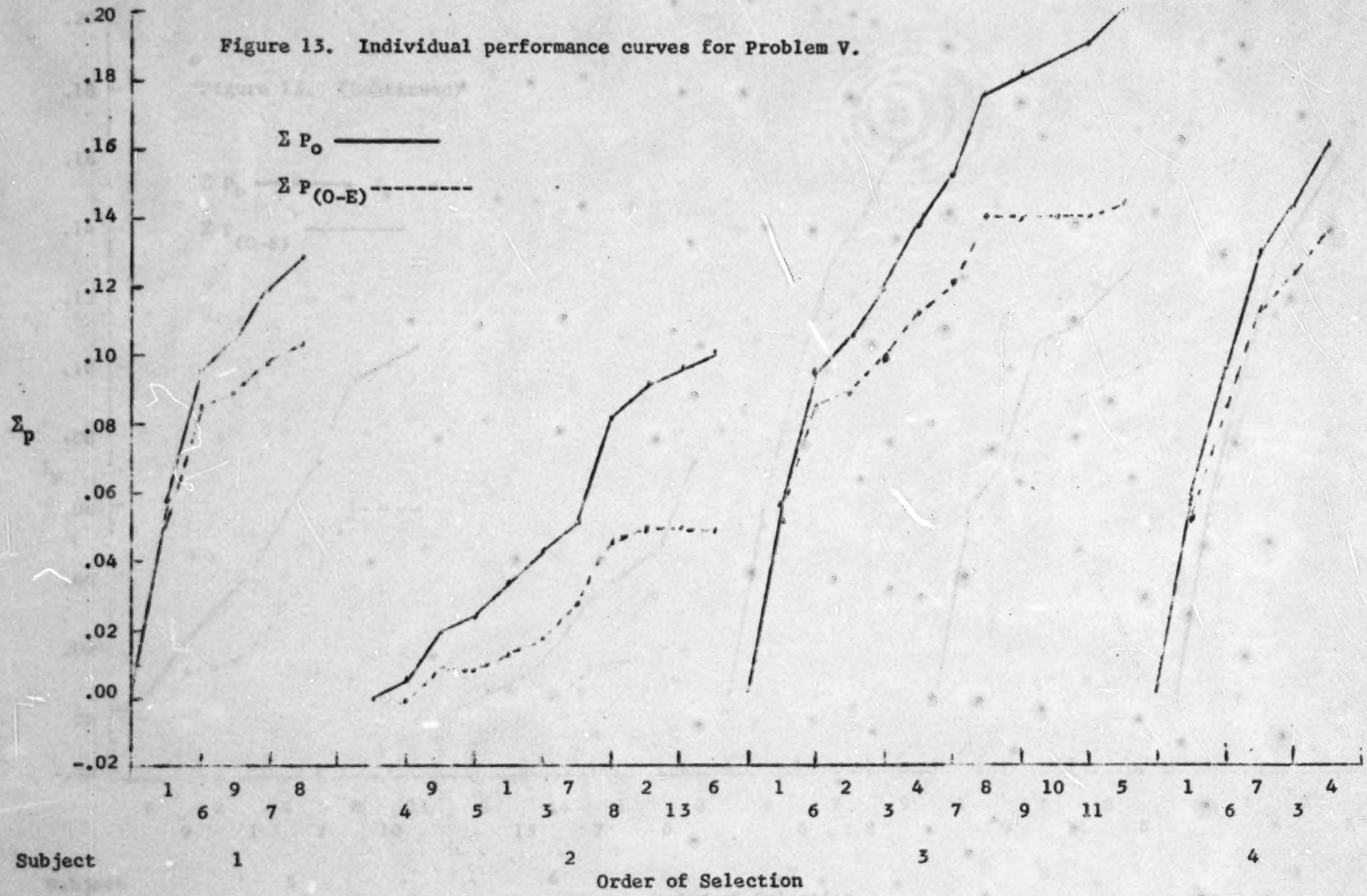


Figure 13. (Continued)

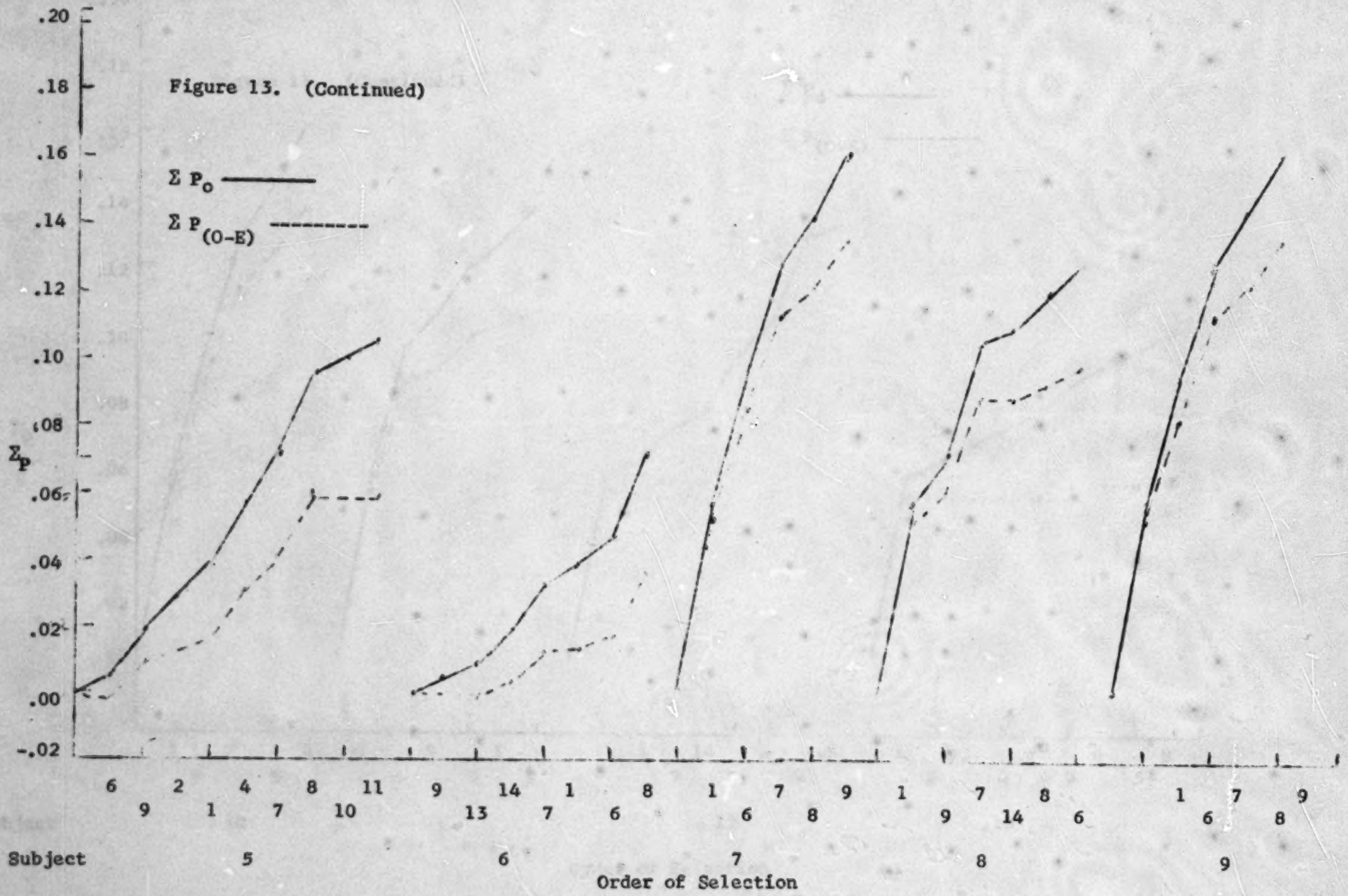


Figure 13. (Continued)

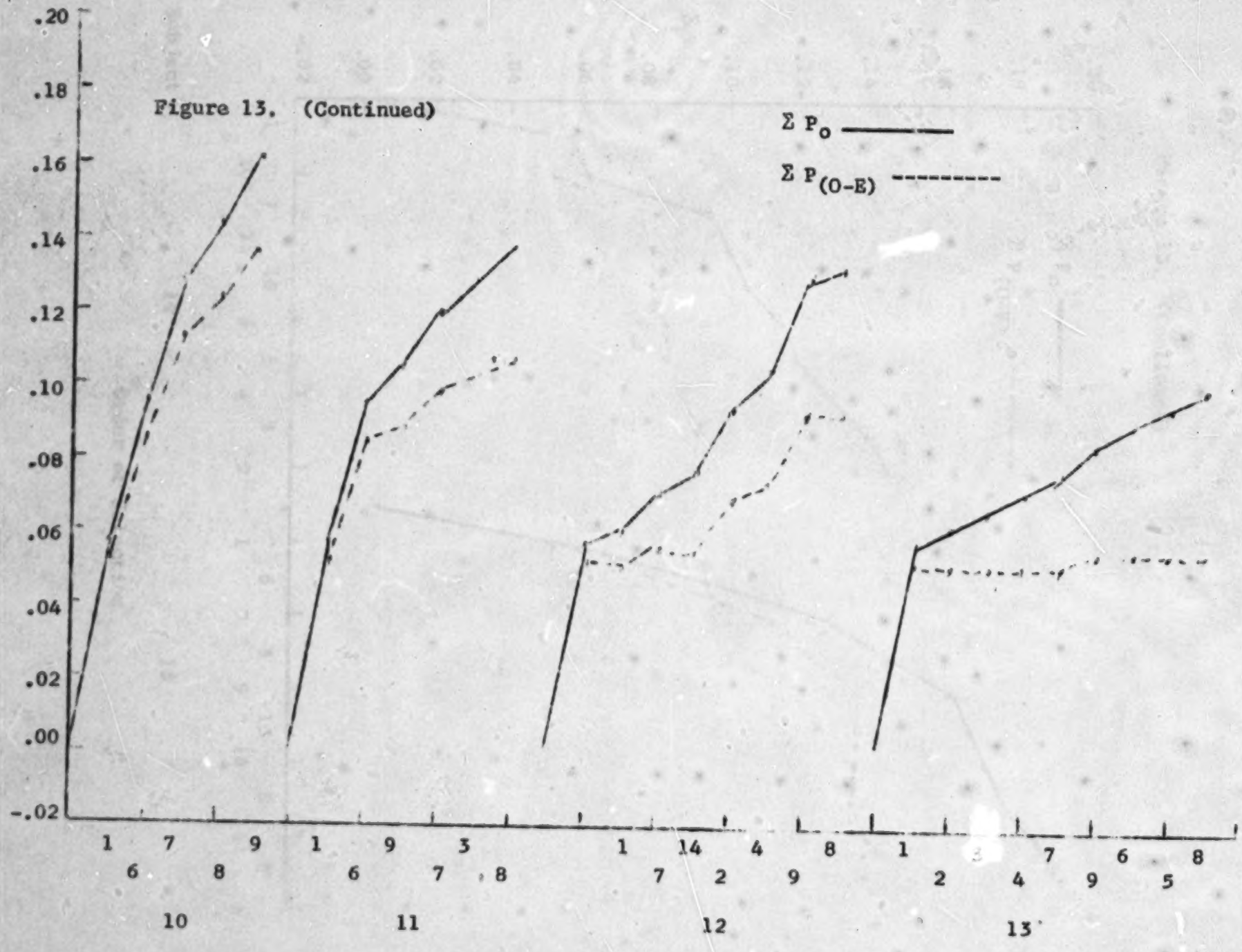
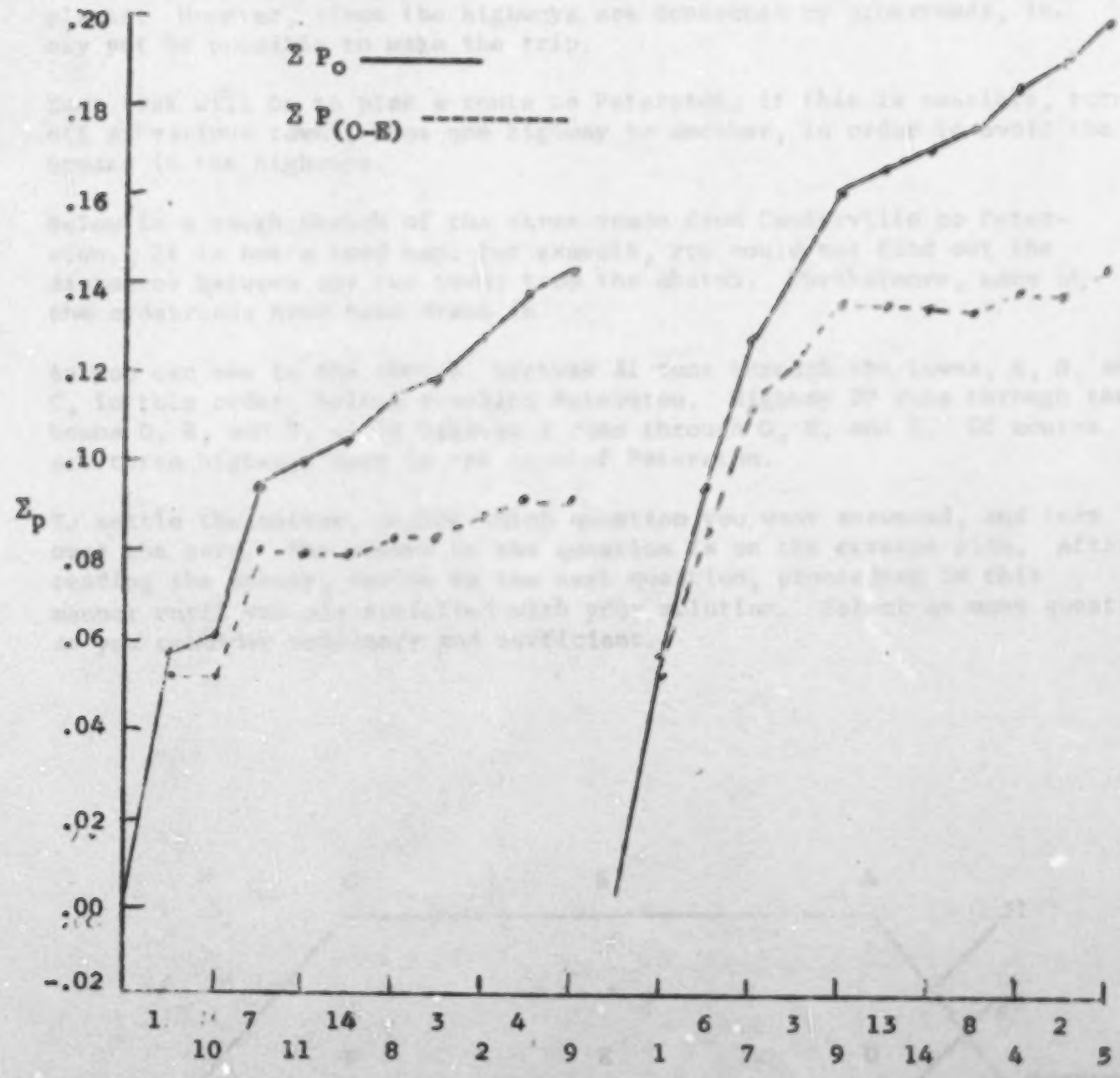


Figure 13. (Continued)



Instructions for Problem *

You wish to drive from Centerville to Peterston. The latter is due East of Centerville. There are three different roads, Highway Numbers 31, 27, and 9 which run from the first to the second city. You are going to start out on Highway 31.

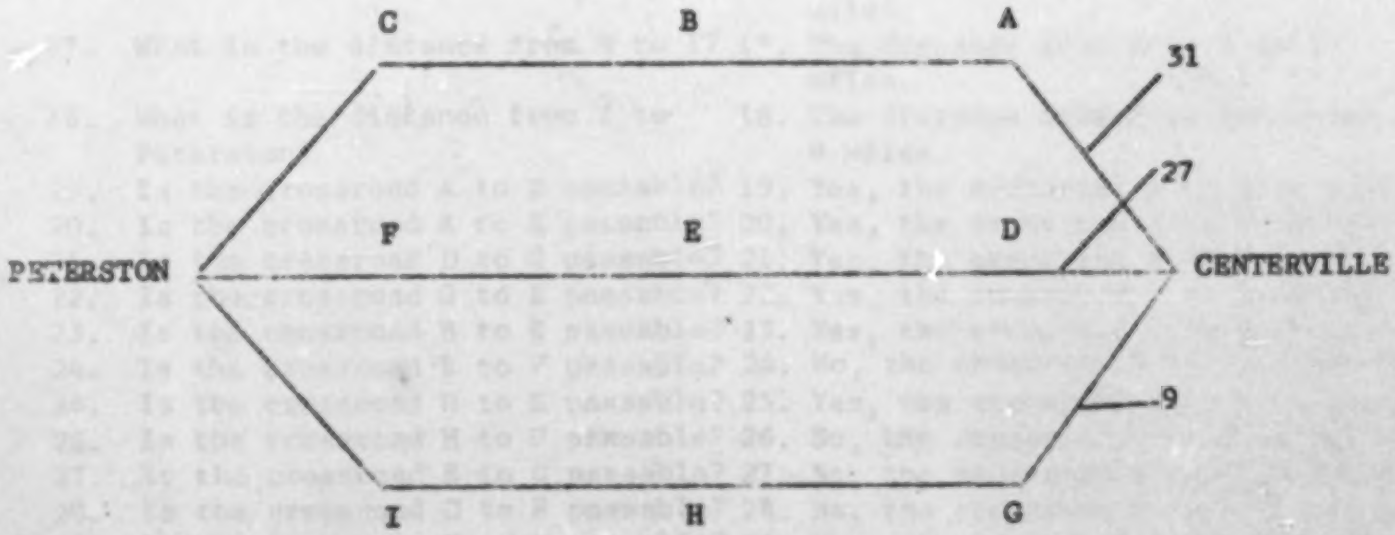
A recent storm has made each of the highways impassable in two places. However, since the highways are connected by crossroads, it may yet be possible to make the trip.

Your task will be to plan a route to Peterston, if this is possible, turning off at various towns, from one highway to another, in order to avoid the breaks in the highways.

Below is a rough sketch of the three roads from Centerville to Peterston. It is not a road map; for example, you could not find out the distances between any two towns from the sketch. Furthermore, none of the crossroads have been drawn in.

As you can see in the sketch, Highway 31 runs through the towns, A, B, and C, in this order, before reaching Peterston. Highway 27 runs through the towns D, E, and F, while Highway 9 runs through G, H, and I. Of course, all three highways meet in the town of Peterston.

To settle the matter, decide which question you want answered, and turn over the card. The answer to the question is on the reverse side. After reading the answer, decide on the next question, proceeding in this manner until you are satisfied with your solution. Select as many questions as you consider necessary and sufficient.



Questions Employed in Problem I
And Corresponding Answers

Question	Answer
1. Where is the first break on Highway 31?	1. The first break on Highway 31 is 6 miles East of A.
2. Where is the second break on Highway 31?	2. The second break on Highway 31 is 4 miles West of C.
3. Where is the first break on Highway 27?	3. The first break on Highway 27 is 1 mile East of D.
4. Where is the second break on Highway 27?	4. The second break on Highway 27 is 10 miles East of D.
5. Where is the first break on Highway 9?	5. The first break on Highway 9 is 1 mile East of G.
6. Where is the second break on Highway 9?	6. The second break on Highway 9 is 2 miles East of I.
7. What is the distance from Centerville to A?	7. The distance from Centerville to A is 10 miles.
8. What is the distance from A to B?	8. The distance from A to B is 10 miles.
9. What is the distance from B to C?	9. The distance from B to C is 10 miles
10. What is the distance from C to Peterston?	10. The distance from C to Peterston is 8 miles.
11. What is the distance from Centerville to D?	11. The distance from Centerville to D is 6 miles.
12. What is the distance from D to E?	12. The distance from D to E is 8 miles.
13. What is the distance from E to F?	13. The distance from E to F is 8 miles.
14. What is the distance from F to Peterston?	14. The distance from F to Peterston is 4 miles.
15. What is the distance from Centerville to G?	15. The distance from Centerville to G is 10 miles.
16. What is the distance from G to H?	16. The distance from G to H is 10 miles.
17. What is the distance from H to I?	17. The distance from H to I is 10 miles.
18. What is the distance from I to Peterston?	18. The distance from I to Peterston is 8 miles.
19. Is the crossroad A to D passable?	19. Yes, the crossroad A to D is passable.
20. Is the crossroad A to E passable?	20. Yes, the crossroad A to E is passable.
21. Is the crossroad D to G passable?	21. Yes, the crossroad D to G is passable.
22. Is the crossroad G to E passable?	22. Yes, the crossroad G to E is passable.
23. Is the crossroad B to E passable?	23. Yes, the crossroad B to E is passable.
24. Is the crossroad B to F passable?	24. No, the crossroad B to F is not passab
25. Is the crossroad H to E passable?	25. Yes, the crossroad H to E is passable.
26. Is the crossroad H to F passable?	26. No, the crossroad H to F is not passab
27. Is the crossroad E to C passable?	27. No, the crossroad E to C is not passab
28. Is the crossroad C to F passable?	28. No, the crossroad C to F is not passab
29. Is the crossroad F to I passable?	29. Yes, the crossroad F to I is passable.

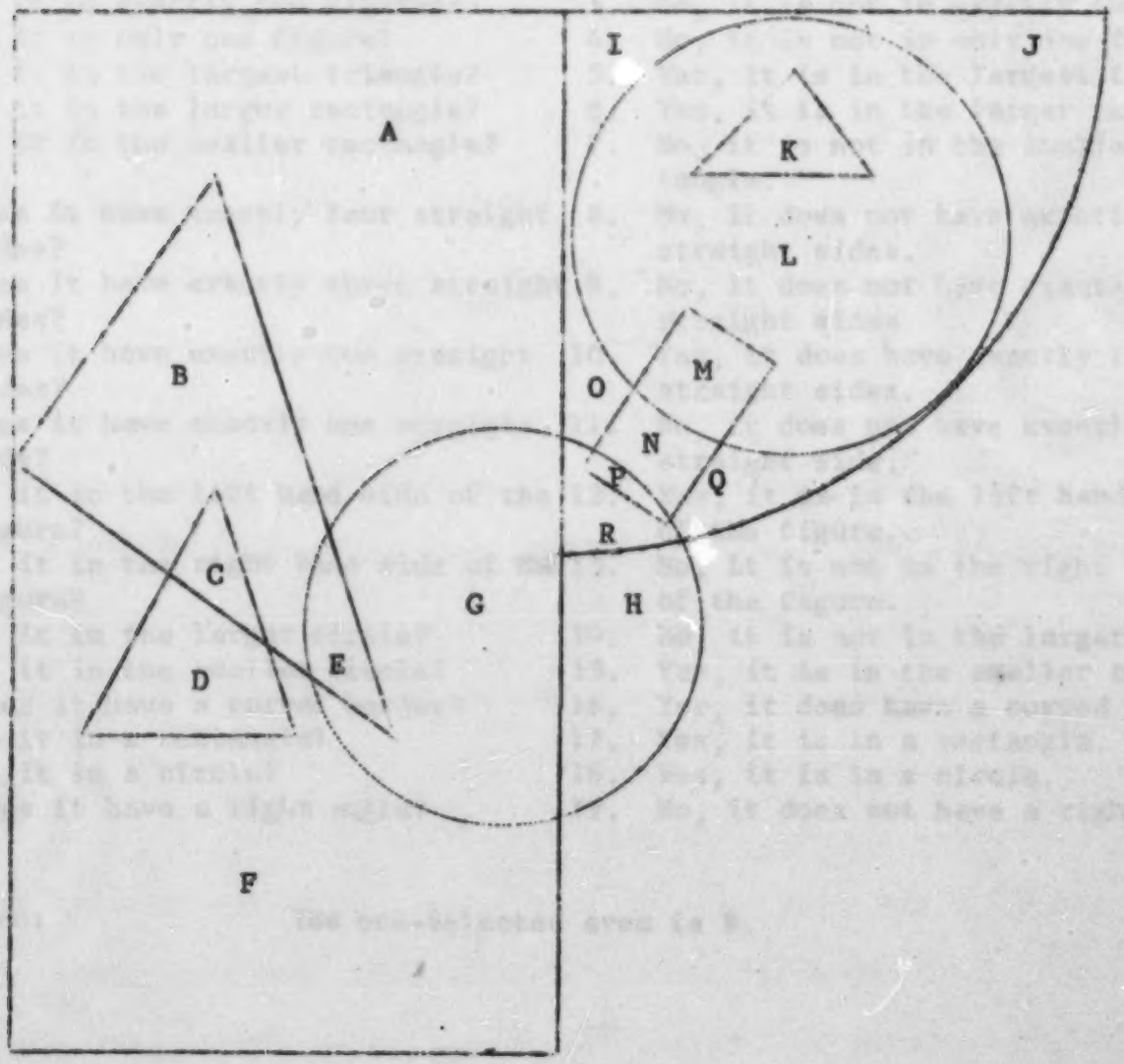
Solution: The open route is Centerville to A to E to H to I to F to Peterston.

Instructions for Problem II

The figure here is made of overlapping geometric figures. You will notice that an area is any enclosed part of the figure that does not have a line through it. One of the areas has been picked at random. Your task is to find out which one it was. To find the particular area, you must discover enough facts about it so that it can be distinguished from other areas. You may discover these facts by using any of the questions you like.

Proceed by reading over all the questions. Then decide on the first question you would like to have answered, and write its number on the page provided. Then take the card from the folder, and read the answer on the back of the card. After having read the answer, decide on the next question you would like to have answered. Write down its number, and take the card from the folder. When you are satisfied that you have arrived at the answer, stop drawing cards, and write down your answer. Remember, you may use as many of the cards as you need to find the correct area, but don't draw any more than you need.

Problem II



Questions Employed in Problem II
And Corresponding Answers

Question	Answer
1. Is it in exactly four figures?	1. No, it is not in exactly four figures.
2. Is it in exactly three figures?	2. Yes, it is in exactly three figures.
3. Is it in exactly two figures?	3. No, it is not in exactly two figures.
4. Is it in only one figure?	4. No, it is not in only one figure.
5. Is it in the largest triangle?	5. Yes, it is in the largest triangle.
6. Is it in the larger rectangle?	6. Yes, it is in the larger rectangle.
7. Is it in the smaller rectangle?	7. No, it is not in the smaller rectangle.
8. Does it have exactly four straight sides?	8. No, it does not have exactly four straight sides.
9. Does it have exactly three straight sides?	9. No, it does not have exactly three straight sides.
10. Does it have exactly two straight sides?	10. Yes, it does have exactly two straight sides.
11. Does it have exactly one straight side?	11. No, it does not have exactly one straight side.
12. Is it in the left hand side of the figure?	12. Yes, it is in the left hand side of the figure.
13. Is it in the right hand side of the figure?	13. No, it is not in the right hand side of the figure.
14. Is it in the larger circle?	14. No, it is not in the larger circle.
15. Is it in the smaller circle?	15. Yes, it is in the smaller circle.
16. Does it have a curved border?	16. Yes, it does have a curved border.
17. Is it in a rectangle?	17. Yes, it is in a rectangle.
18. Is it in a circle?	18. Yes, it is in a circle.
19. Does it have a right angle?	19. No, it does not have a right angle.

Solution: The pre-selected area is E.

Instructions for Problem III

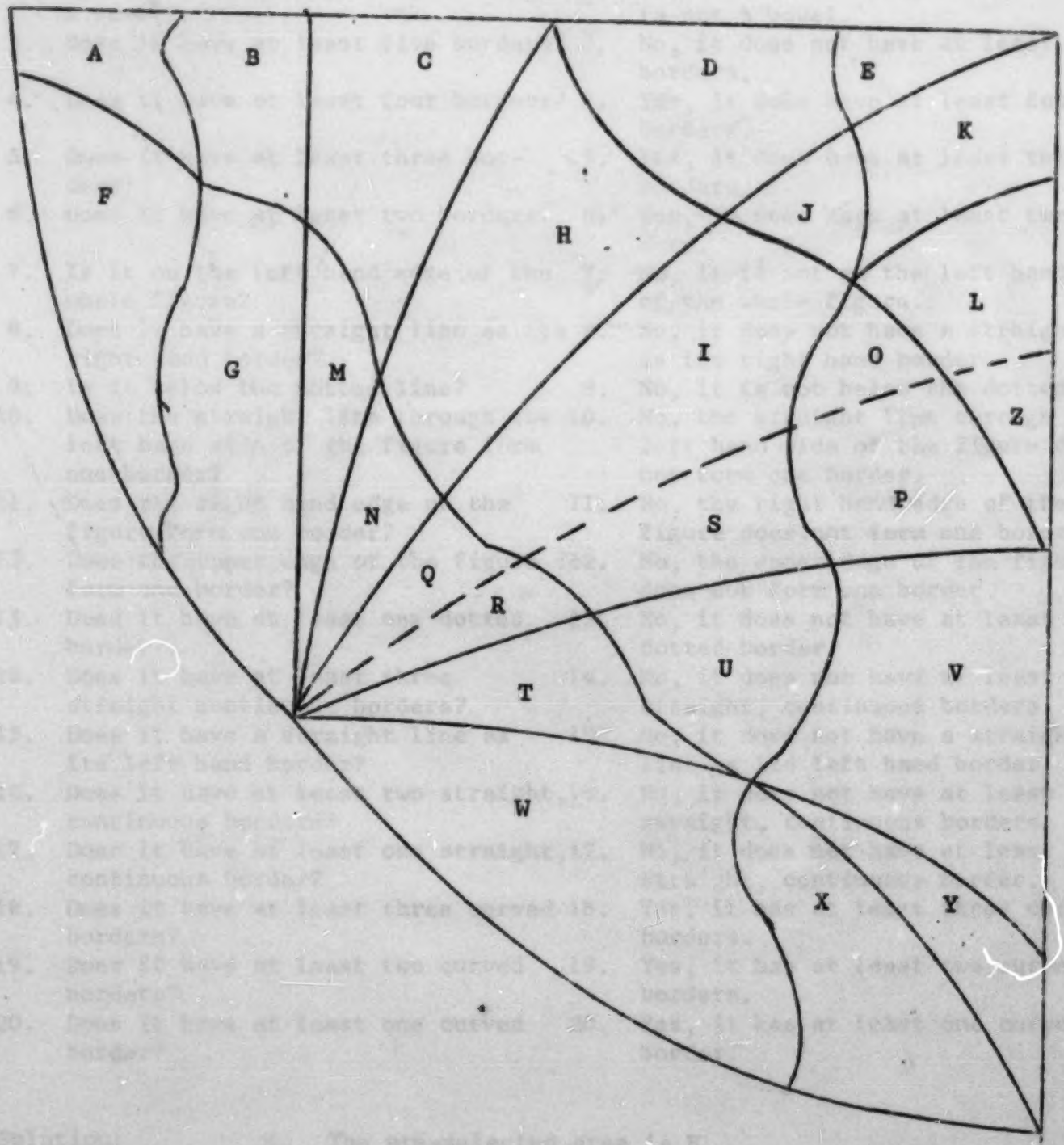
The figure is composed of straight, curved, and dotted lines. Lines that are not dotted are called continuous lines. You may notice that a line that is mostly curved may appear straight for a short distance; you must therefore look at the whole line, and not just a small part of it to decide whether it is straight or curved.

The areas are labeled A through Z. One of them has been picked at random. Your task is to determine which one it was.

To find the particular area, you must discover enough facts about it so that it can be distinguished from the other areas. You may discover these facts by using any of the questions you like to arrive at the answer.

Proceed by reading over all the questions. Decide on the first question you would like to have answered and write its number on the page provided. Then withdraw the card from the folder, and read the answer on the back of the card. After having read the answer on the back of the card, decide on the next question you would like to have answered. Write down its number and withdraw the card. When you are satisfied that you have arrived at the answer, stop drawing cards, and write down your answer. Remember, you may draw as many cards as you need to find the correct area, but don't draw any more than you need.

Problem III



Questions Employed in Problem III
And Corresponding Answers

Question	Answer
1. Is it one of the larger areas?	1. Yes, it is one of the larger areas.
2. Is the letter designating the area a vowel?	2. No, the letter designating the area is not a vowel.
3. Does it have at least five borders?	3. No, it does not have at least five borders.
4. Does it have at least four borders?	4. Yes, it does have at least four borders.
5. Does it have at least three borders?	5. Yes, it does have at least three borders.
6. Does it have at least two borders?	6. Yes, it does have at least two borders.
7. Is it on the left hand edge of the whole figure?	7. No, it is not on the left hand edge of the whole figure.
8. Does it have a straight line as its right hand border?	8. No, it does not have a straight line as its right hand border.
9. Is it below the dotted line?	9. No, it is not below the dotted line.
10. Does the straight line through the left hand side of the figure form one border?	10. No, the straight line through the left hand side of the figure does not form one border.
11. Does the right hand edge of the figure form one border?	11. No, the right hand edge of the figure does not form one border.
12. Does the upper edge of the figure form one border?	12. No, the upper edge of the figure does not form one border.
13. Does it have at least one dotted border?	13. No, it does not have at least one dotted border.
14. Does it have at least three straight continuous borders?	14. No, it does not have at least three straight, continuous borders.
15. Does it have a straight line as its left hand border?	15. No, it does not have a straight line as its left hand border.
16. Does it have at least two straight, continuous borders?	16. No, it does not have at least two straight, continuous borders.
17. Does it have at least one straight, continuous border?	17. No, it does not have at least one straight, continuous border.
18. Does it have at least three curved borders?	18. Yes, it has at least three curved borders.
19. Does it have at least two curved borders?	19. Yes, it has at least two curved borders.
20. Does it have at least one curved border?	20. Yes, it has at least one curved border.

Solution: The pre-selected area is H.

Instructions for Problem IV

Pretend that lutts and mipps represent a new way of measuring distance, and that dars, wors, and mirs represent a new way of measuring time.

A man drives from Town A to Town D. He drives through Town B and Town C in order to reach Town D. Your task is to determine how many wors the entire trip took.

Remember, the words for different distances are mipps and lutts, while the words for different times are mirs, wors, and dars.

Read over the questions in the folder, and decide which one you would like to have answered first. Tell the examiner its number, and read the answer on the back of the card. Do not select more questions than you need to answer the question, but don't hesitate to select any question that you feel you need.

Questions Employed in Problem IV
And Corresponding Answers

	Question		Answer
1.	How far is it from A to B?	1.	It is 4 lutts from A to B.
2.	How far is it from B to C?	2.	It is 8 lutts from B to C.
3.	How far is it from C to D?	3.	It is 10 lutts from C to D.
4.	What is a lutt?	4.	A lutt is 10 mipps.
5.	What is a mipp?	5.	A mipp is a way of measuring distance.
6.	How many mipps are there in a mile?	6.	There are 2 mipps in a mile.
7.	What is a dar?	7.	A dar is 10 wors.
8.	What is a wor?	8.	A wor is 5 mirs.
9.	What is a mir?	9.	A mir is a way of measuring time.
10.	How many mirs are there in an hour?	10.	There are 2 mirs in an hour.
11.	How fast does the man drive from A to B?	11.	The man drives from A to B at the rate of 24 lutts per wor.
12.	How fast does the man drive from B to C?	12.	The man drives from B to C at the rate of 30 lutts per wor.
13.	How fast does the man drive from C to D?	13.	The man drives from C to D at the rate of 30 lutts per wor.

Solution:

$\frac{23}{30}$ wors

Instructions for Problem V

There are objects called Ks. Your task is to find out how many of the Ks are also Ms. K might be a shorthand way of saying college student, and M a shorthand way of saying Cub fan. Then the problem would be to find out how many college students are Cub fans. Or K might stand for Democrat, and M stand for red haired. Then the problem would be to find out how many Democrats are red haired.

Begin by reading over all the questions. Decide on the first question you would like to have answered, and write its number on the page provided. Then take the card from the folder, and read the answer on the back. Then decide on the next question you would like to have answered, write down its number and take the card from the folder. When you are satisfied that you have arrived at the answer stop taking cards and write down your answer. Remember, you may use as many cards as you need to find the answer, but don't draw any more cards than you need.

Questions Employed in Problem V
And Corresponding Answers

Question	Answer
1. How many kinds of Ks are there?	1. There are three kinds: P, B, and L.
2. How many of the Ks are Ps?	2. One half of the Ks are Ps.
3. How many of the Ks are Bs?	3. One fourth of the Ks are Bs.
4. How many of the Ks are Ls?	4. One fourth of the Ks are Ls.
5. How many of the Ks are Ds?	5. None of the Ks are Ds.
6. Is a P also an M?	6. A P is an M only when it is not a K. Ks of the P kind cannot be M.
7. How many Bs are Ms?	7. All Bs that are also Cs are Ms.
8. Are Ks of the B kind also Cs?	8. No, Ks of the B kind are not Cs.
9. How many Ls are M?	9. None of the Ls are M.
10. May a K be both a P and a B?	10. No, a K cannot be both a P and a B.
11. May a K be both a P and an L?	11. No, a K cannot be both a P and an L.
12. May a K be both a B and an L?	12. No, a K cannot be both a B and an L.
13. How many Ds are M?	13. All Ds that are not Cs are M.
14. Are Ks of the D kind also Cs?	14. There are no Ks of the D kind.

Solution: No Ks are Ms.